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AIR-TO-AIR TARGET ACQUISITION: FACTORS AND MEANS OF IMPROVEMENT

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This technical report has been reviewed and is approved for publication.

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This report summarizes the literature on target acquisition with emphasis on target detection and collision avoidance in the air-to-air environment. A comprehensive, annotated bibliography is included.

Major factors in air-to-air acquisition are discussed, pertinent data are presented, and potential improvements through training are listed. The report is concluded with a description of a research program designed to improve air-to-air detection performance.

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AIR-TO-AIR TARGET ACQUISITION: FACTORS AND MEANS OF IMPROVEMENT

INTRODUCTION

Air-to-air target detection is a required skill for safety purposes in commercial and general aviation, and for tactical purposes in military aviation. While the criticality of this task has been recognized for decades and while major efforts have been devoted to its definition, discussion, and modeling, no ready solutions have been put forth to provide significant performance improvements.

The objective of this current study is to filter the large amount of literature, and recommend for subsequent investigation those factors which might be improved through training or aids. This objective was accomplished by the following steps.

1. All target detection (recognition, acquisition) literature was computer searched, reports were obtained, and all were screened for relevance to the air-to-air problem.

2. A comprehensive bibliography was prepared of all relevant reports and publications. While only a small proportion dealt directly with air-to-air target detection, a major proportion of this selected literature had pertinent, related information. This bibliography is appended to the report.

3. This literature was reviewed, summarized, and categorized into groupings relevant to the stimulus, the task, and the observer. A major section was also devoted to modeling of the visual detection task, as such models form an often useful framework for assessing current knowledge and suggesting future research.

4. Based upon the results of this literature review, a research program is outlined to develop possible improvement in air-to-air target detection performance.

OBSERVER AND PHYSICAL CHARACTERISTICS OF THE SEARCH PROBLEM

Stimulus Characteristics

Target Size, Luminance, and Position

The problem of visual search in the air-to-air environment is essentially one of detecting the presence of another aircraft, commonly called the target, with sufficient time to respond appropriately. The ability to detect an object by the unaided human eye is, fundamentally, a function of the apparent size of that object, its position within the field of view, the target's luminance, and the overall luminance of the scene. These physical characteristics of the visual stimulus interact to determine the target's threshold detectability.

The physiological and anatomical properties of the observer set the limits on the range of detectability and the threshold of detection. Thus, the stimulus characteristics should be understood in the context of their effect on the visual perception of the observer. One of the most extensive psychophysical studies of those fundamental variables was conducted by Blackwell (25), in which stimulus area, adaptation luminance, and stimulus contrast were systematically varied within a 10 deg radius field to obtain approximately 450,000 data points for threshold responses. The overall result of his work was to produce a set of threshold curves relating these three parameters. As might be expected intuitively, it was found that at a given threshold contrast the target size necessary for detection decreases as overall luminance increases (Figure 1). Stated differently, larger targets require less overall luminance and less contrast for threshold detection. These findings are consistent with the results derived by Zaitzeff (236) from the data of Miller (158) that visual acuity generally increases with increasing luminance over a more extensive range representative of the air-to-air search environment. This trend can be observed in Figure 2.

The contrast threshold functions of Figure 1 reveal two other interesting phenomena. The discontinuities present at approximately 2.5×10^{5} cd/m^{2} can be explained in terms of a shift from foveal vision to parafoveal vision at lower luminance levels. In addition, it can be observed that threshold contrast becomes relatively constant with respect to adaptation luminance at high luminance levels for a given

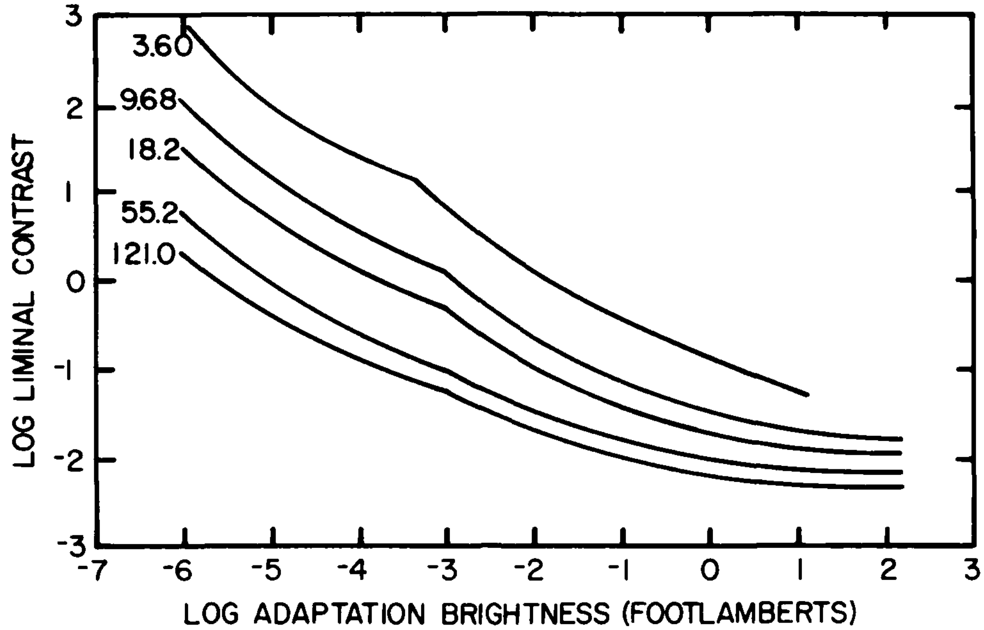

Figure 1. Arithmetical mean of threshold contrasts, plotted as function of adaptation luminance, five stimulus areas (25).

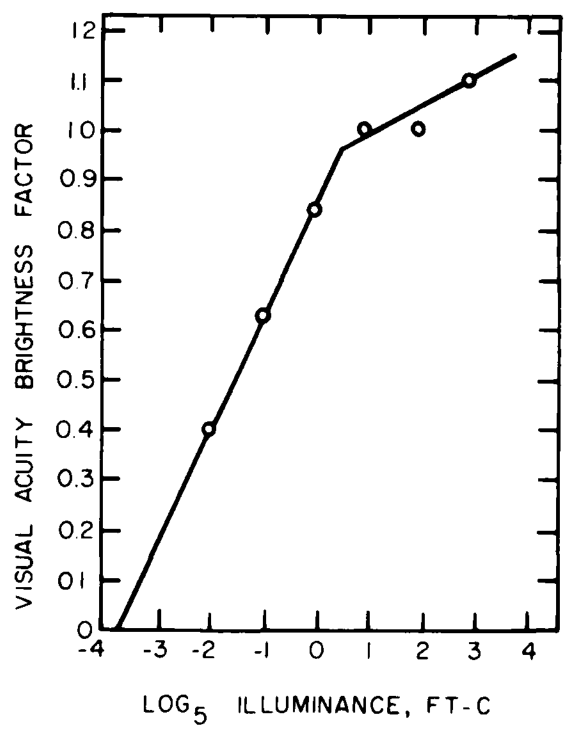

Figure 2. Visual acuity as a function of illumination (233, p. 30).

stimulus area. Moreover, Blackwell (25) postulates a fundamental property of the eye, the "critical visual angle" beyond which area x luminance ceases to be a constant, as indicated in Figure 3.

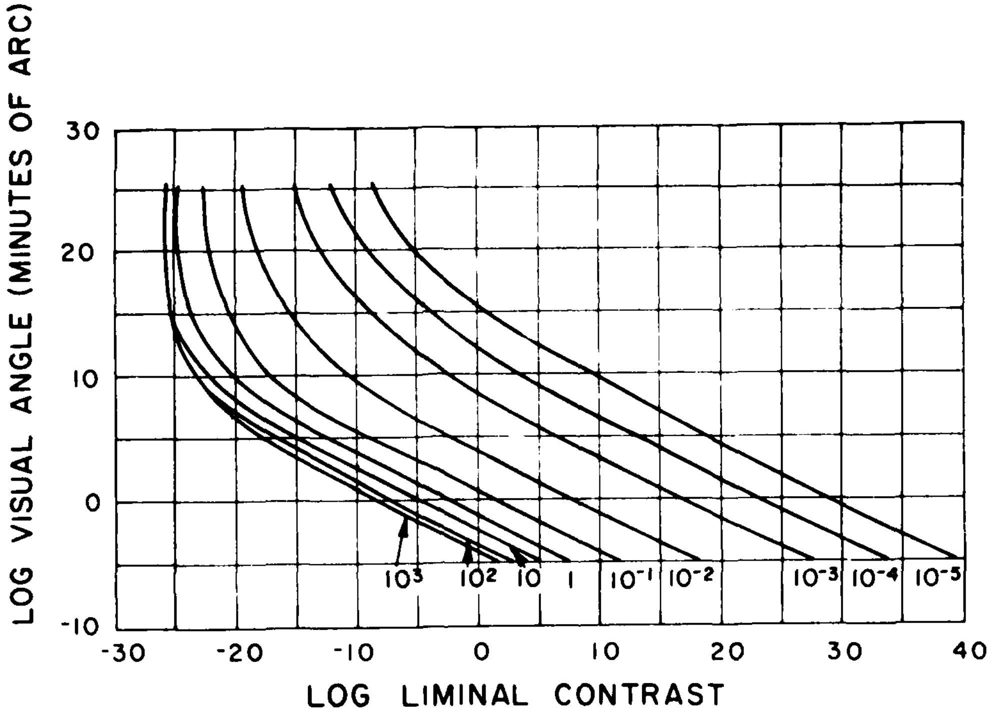

Figure 3. Each curve represents the relation between threshold contrast and stimulus area for a given adaptation luminance (25).

Contrast is defined in this context as the ratio of the difference in target and background luminance to the prevailing background luminance:

$$C = (L_t - L_o)/L_o \qquad (1)$$

Blackwell (25) also found that, in general, equal positive and negative contrasts are equally detectable.

Target luminance is thus the target property which largely determines contrast and influences detectability. The target luminance, L_o, can be obtained by multiplying the illuminance on the surface, L_s, by the target directional reflectance factor, R_t. However, it should be noted that a simple increase of target luminance may reduce contrast in full daylight conditions, thereby interfering with detection if the target is darker than the background initially.

The apparent size of a target is a measure of the angle (α, in minutes of arc) subtended by the target at the eye of the observer. It can be approximated for small targets (α < 5 min) to be the angular diameter of a circle of equivalent area A_o:

$$\alpha = 1293\ A_o^{(1/2)} R \text{ or } 2/R \sqrt{A_t/\pi}\ , \qquad (2)$$

where

R is the range to the target, and

A_t is the equivalent target area.

Alternatively, the angular subtense of a given size object (d) at a known range (R) may be approximated by arctan (d/R) for small angles.

Shape has been found to be an unimportant parameter for detection of small targets (4; 135). Yet Lamar et al. (138) did find contrast threshold to rise as targets became narrower and longer, i.e., as the ratio of length to width increases (Figure 4).

For the suprathreshold case, as well, Miller and Ludvigh (162) found that as target size increased, the likelihood of detecting it in a given time interval also increased. One explanation for the greater detectability of larger targets is given by Lamar et al. (137) according to the quantum theory of cone vision which considers the minimum number of these retinal receptors necessary for the perception of an image. Instead of looking at size in terms of diameter, Lamar et al. considered the perimeter of the retinal image and found that average retinal threshold contrast decreases by a fractional power with increasing retinal image perimeter (Figure 5). Lamar et al. (138) concluded that contrast is not judged over the area of the target but across its boundary.

While the Blackwell (25) data have provided a useful source for foveal detection thresholds, the investigations of off-axis detectability by Taylor (205) have served as a standard source for peripheral threshold data. It is shown in Figure 6 that the position of the target in the field of view is another determining factor in detection. As the target is moved outward from the fixational axis, greater and greater contrasts are necessary for detection thresholds to be reached. This is particularly true for smaller targets and is directly pertinent to the development of visual search models, as will be discussed in a subsequent section.

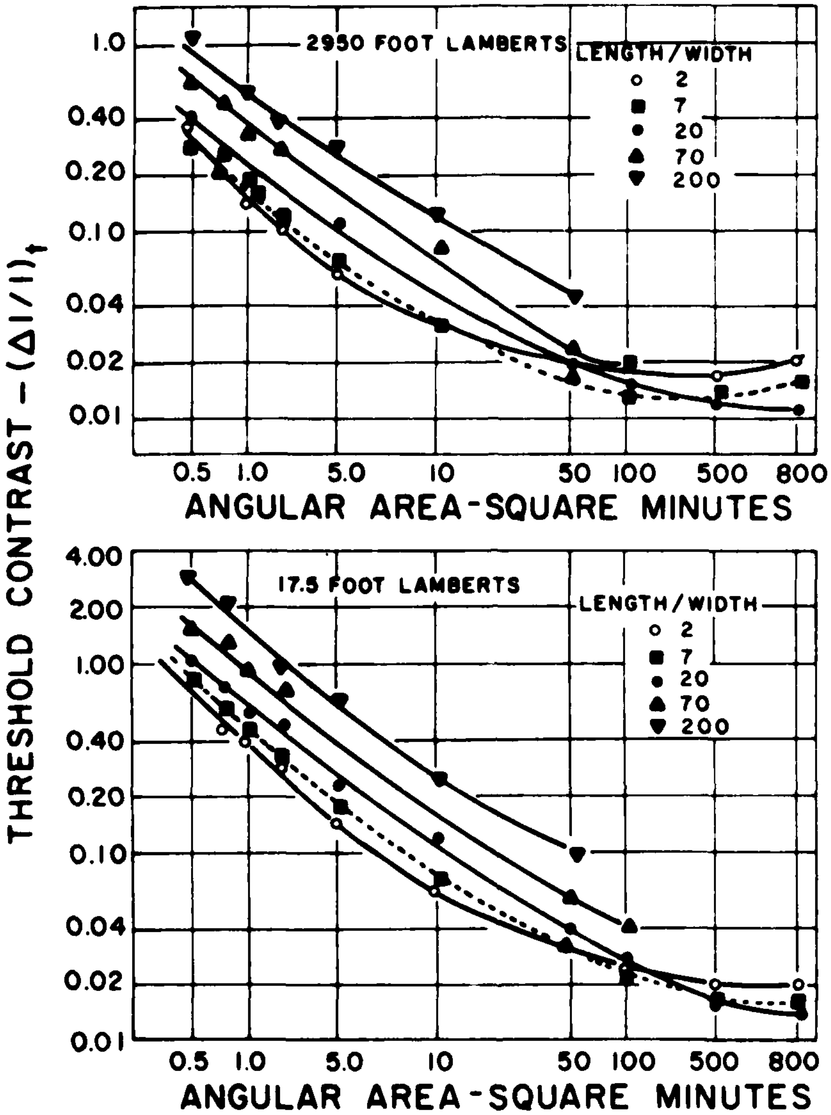

Figure 4. Relation between area and threshold contrast for different ratios of length to width of rectangular target (138).

The threshold gradient curves of Sloan (197), although derived from a rather limited subject sample, also show, for the light adapted eye, that higher levels of luminance are needed for detection of a target of given size as the object is moved into the periphery. This is equivalent to a requirement of greater object contrast or reduced range for target detection in the periphery.

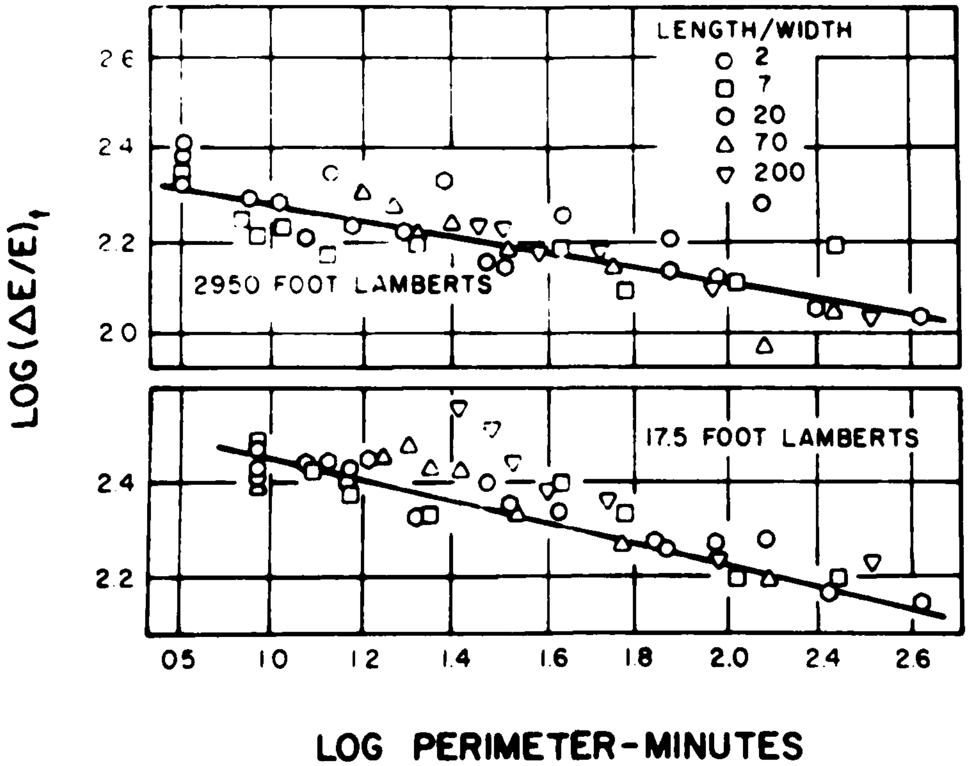

Figure 5. Relationship between logarithm of retinal threshold contrast and image perimeter (138).

Intervening Media

Background Luminance and Target/Background Contrast. The physical properties of the stimulus are generally mitigated by the intervening media between the observer and the target. Thus, target contrast is not a simple property of the object but must be specified by the overall background luminance as well. Typical values of sky background luminance for various conditions are provided by Townsend and Mace (214) in Table 1.

In the case of nonuniform backgrounds, Taylor (205) found, for an 8-deg circular background, that immediate target background luminance is the prime determinant of threshold. These effects, which may be of limited utility, are shown in Figure 7. It is generally agreed, however, that local target contrast is the most critical objective factor in target acquisition. Although consensus has not been reached concerning the exact mechanism of contrast detection or its best mathematical formulation, contrast remains a central parameter in virtually all research of the acquisition process and its modeling.

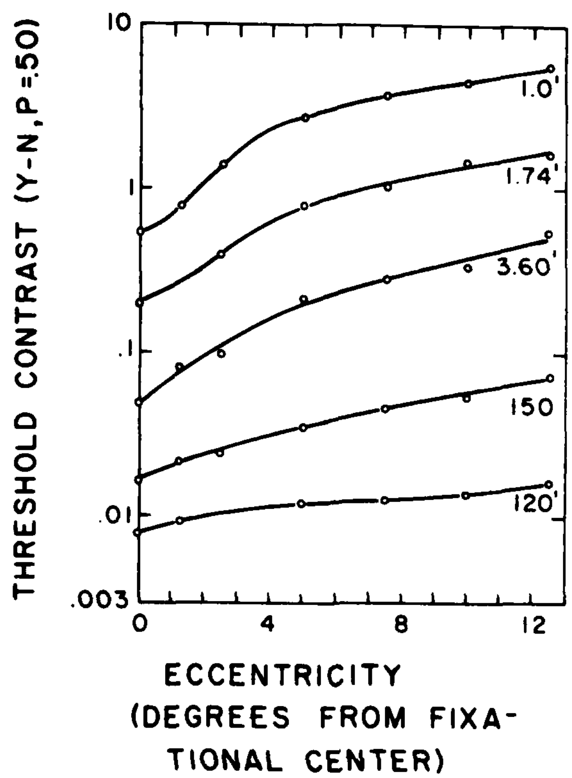

Figure 6. Threshold contrast as function of retinal position and target size for binocular photopic vision (202).

In an early report, Koomen (127) discussed the possible critical effects of low contrast levels on the detection of aircraft at high altitudes. He stated that the contrast of a plane of average reflectance may hover around the zero value. Short (195) reports similarly that under typical daylight conditions, the aircraft contrast ratio generally ranges from 0 to 5.0.

<u>The Atmosphere</u>. The atmosphere acts to reduce the inherent contrast of the target, C_o, to an apparent value at a given range, C_r. A thorough investigation regarding the scattering of light through the atmosphere was conducted by Middleton (157), in which it was shown that luminous flux is attenuated as a function of range. This relation is expressed as $F_r = F_o e^{-\sigma r}$, where σ is the extinction coefficient, and r is range.

The extinction coefficient is defined in terms of the prevailing visibility conditions as $\sigma = 3.912/V$, where V is

TABLE 1. NOMINAL LUMINANCE OF THE HORIZON SKY (214, p. 5).

Subjective condition	Luminances, cd/m^2
Clear day, sunlit cloud	10^4
Overcast day	10^3
Heavily overcast day	10^2
Sunset, overcast	10
Fairly bright moonlight	10^{-2}
Clear night, moonless	10^{-3}
Overcast night, moonless	10^{-4}

FIXATION AT	TARGET LOCATION WITHIN NON-UNIFORM FIELD				
	A	B	C	D	E
C	7.90	2.23	0.616		
D		3.13	1.28	0.763	
E			3.11	2.03	1.64

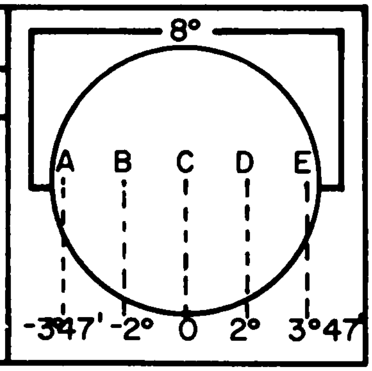

Figure 7. Threshold contrast, 1-min circular targets seen against 8-deg background of nonuniform luminance w/dark shroud (205).

meterological sighting range based on atmospheric conditions. Meteorological range is defined as that distance for which the contrast transmittance of the atmosphere is 2%. Thus, apparent contrast is given by $C_r = C_o e^{-3.912 R/V}$. Therefore, light reflected or generated by the object and its background forms a predictable retinal image contrast after having been attenuated by the intervening atmosphere.

<u>Type of Search Field</u>. The atmospheric conditions and flight path determine the type of search field present to the observer. Thus, the search field may range from the vast empty field at high altitudes to a complex landing approach field under clear or overcast skies. Such different types of possible search fields provide variations in the basic problem of target acquisition.

For example, during takeoff and landing, very little time is available for search or scanning. Depending on the field of view encountered, Bloomfield and Modrick (36) suggest that the eyes of the observer are continually being adjusted to provide an appropriate view of whatever is of interest at a given moment. This multidimensional fluctuation in the search field makes parametric modeling of the background clutter difficult if not impossible for all flight segments.

<u>Glare</u>. Glare within the visual field can become a degrading factor in the acquisition task. Sources of glare may include direct rays from the sun or reflected light off the sea or cloud cover below. Reflections off surrounding

plane parts may contribute to the glare problem. In general, glare may be defined as a source of luminance within the visual field that is sufficiently greater than the luminance level to which the eyes are adapted to cause reduced performance.

One laboratory study (by Luckiesh and Moss) reported in McCormick (154) investigated the effects of glare from various angular positions within the field of view. The general results, given in Figure 8, indicate that the degrading effects of glare become worse as the glare source gets closer to the line of sight.

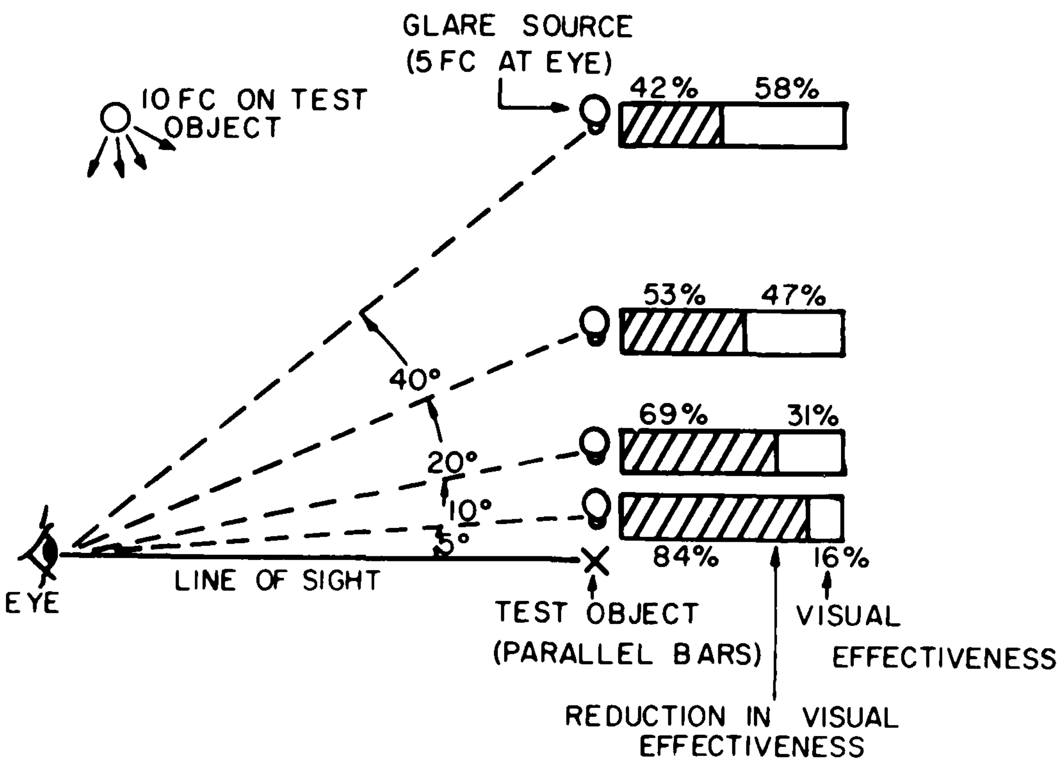

Figure 8. Effects of direct glare on visual effectiveness (154).

Aircraft Structure. Perhaps the most significant limitation imposed on the field of view of the searching observer is the structure of the aircraft itself. Although the precise degree of canopy masking will vary from aircraft to aircraft, it is reported by Baker (11) that as little as 15%

of the total visual field is available in certain cases. Although the specific data are not provided by Baker, the source of this finding is a 1948 cockpit visibility study conducted by the Civil Aeronautics Authority which reached this conclusion based on line-of-sight limitations and observations of pilots' eye movements during flight.

Several reports, however, do provide cockpit visibility layouts which clearly indicate the restricted field of view available to the pilot. Ferguson and Goodson (78) furnish cockpit information for the F-4 aircraft (Figure 9), while Andrews (4) presents approximate cockpit visibility for the pilot of a PA-28 aircraft (Figure 10). Andrews notes that pilots could conceivably search areas quite far to the left but would remain severely limited in overcoming the visibility problems posed by searching toward the right. The canopy also greatly restricts visibility below and above the narrow band of elevation angle defined by the window openings.

It is essentially beyond the capability of the human observer to overcome such "built-in" limitations upon the field of view. It therefore seems unreasonable to expect a pilot or flight crew not only to acquire any target which may be masked by aircraft structure, but also to maintain a line of sight after an initial detection. The fact that a large number of mid-air collisions (occurring under conditions of clear visibility) have been attributed to a human failure to acquire or maintain visual separation, seems to argue for the use of electronic aiding devices (the Pilot Warning Indicator (PWI) System will be treated in later sections) and/or that more specific information be provided to commercial and general aviation aircraft in potential collision situations by Air Traffic Control (ATC) networks.

Moreover, the cockpit canopy attenuates available contrast by an additional factor caused by the transmissivity of the windscreen, which, on the average, can be considered to be equal to 96%. The presence of scratches and nonuniformities in the windscreen may also distort the available image. This problem is aggravated further by curved windscreens (e.g., F-111).

Relative Motion and Available Search Time

In the air-to-air search situation, the essential task is one of detecting a moving target from a moving aircraft. Although target motion is not likely to have a detrimental effect on detection below a rate of 10 deg/sec angular velocity (70), it does, of course, contribute to relative motion or closing rate which may ultimately (at short range) exceed this angular velocity and thus affect detection.

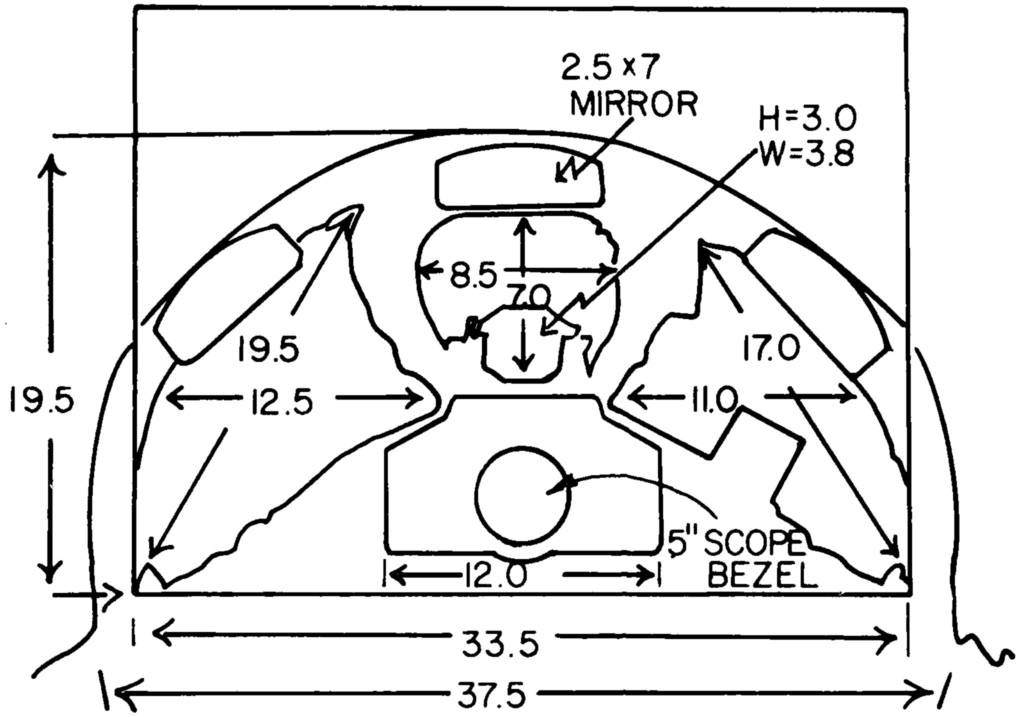

Figure 9. Scaled dimensions of F-4 cockpit (all measurements in inches) (78).

The closing rate between two aircraft on a collision course predetermines the time available for search, detection, and avoidance, and thereby becomes a key limiting variable. In the case of a single pilot, the time available for search is also generally limited, by the time necessary to devote to the primary task of navigation. Although search is a vital function in flying, it remains a secondary task in many situations to the pilot.

When two aircraft, (1) and (2) respectively, are approaching one another at the same altitude, at velocities of V1 and V2, respectively, the time before one passes abeam the other is given by:

$$t = (d)/V_1 + V_2(\cos |H_1 - (180 + H_2)|). \qquad (3)$$

where d is distance initially, H_1 is heading of aircraft (1), and H_2 is heading of aircraft (2). The term "search time" has a more specific meaning in the context of the observer having been alerted to the presence of a target. In this case, it refers to the time it takes to detect the target somewhere in the field of view, where searching has become the primary task.

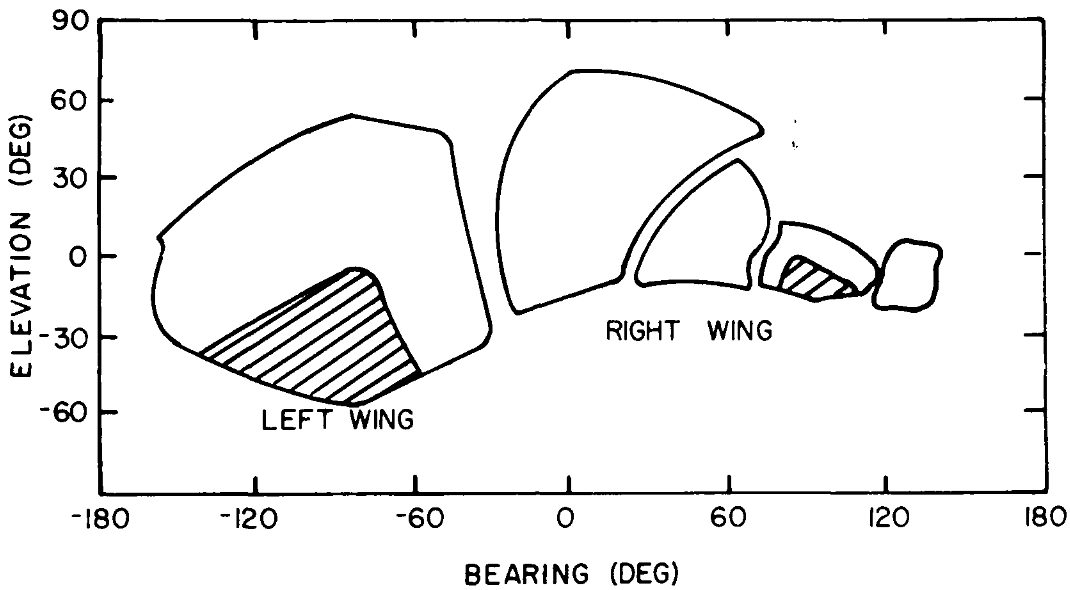

Figure 10. Approximate cockpit visibility for pilot in left seat of PA-28 (4, p. 33).

<u>Range</u>

Range refers to the distance between the observer and the target at the time a detection is made or required. If a target were located outside the limits of meteorological visibility, it would be highly unlikely that detection could occur. However, at some range less than the liminal object distance (the point at which an object is large enough for detection) the observer becomes aware of "seeing" the target. This is called the sighting range.

The relation between range and detection has, in fact, been found by Parkes (177) to be an inverse linear function in a simulated static search task (Figure 11).

The threshold data of Blackwell (25) were used by Duntley (64) together with an atmospheric attenuation factor to construct nomographic visibility charts for adaptation luminances from 10^{-5} to 10^{3} cd/m^{2}, which permit the limiting range for detection to be found by extrapolation for any set of prevailing conditions. Nomographic charts for full daylight conditions and overcast sky are presented in Figures 12 and 13 (64).

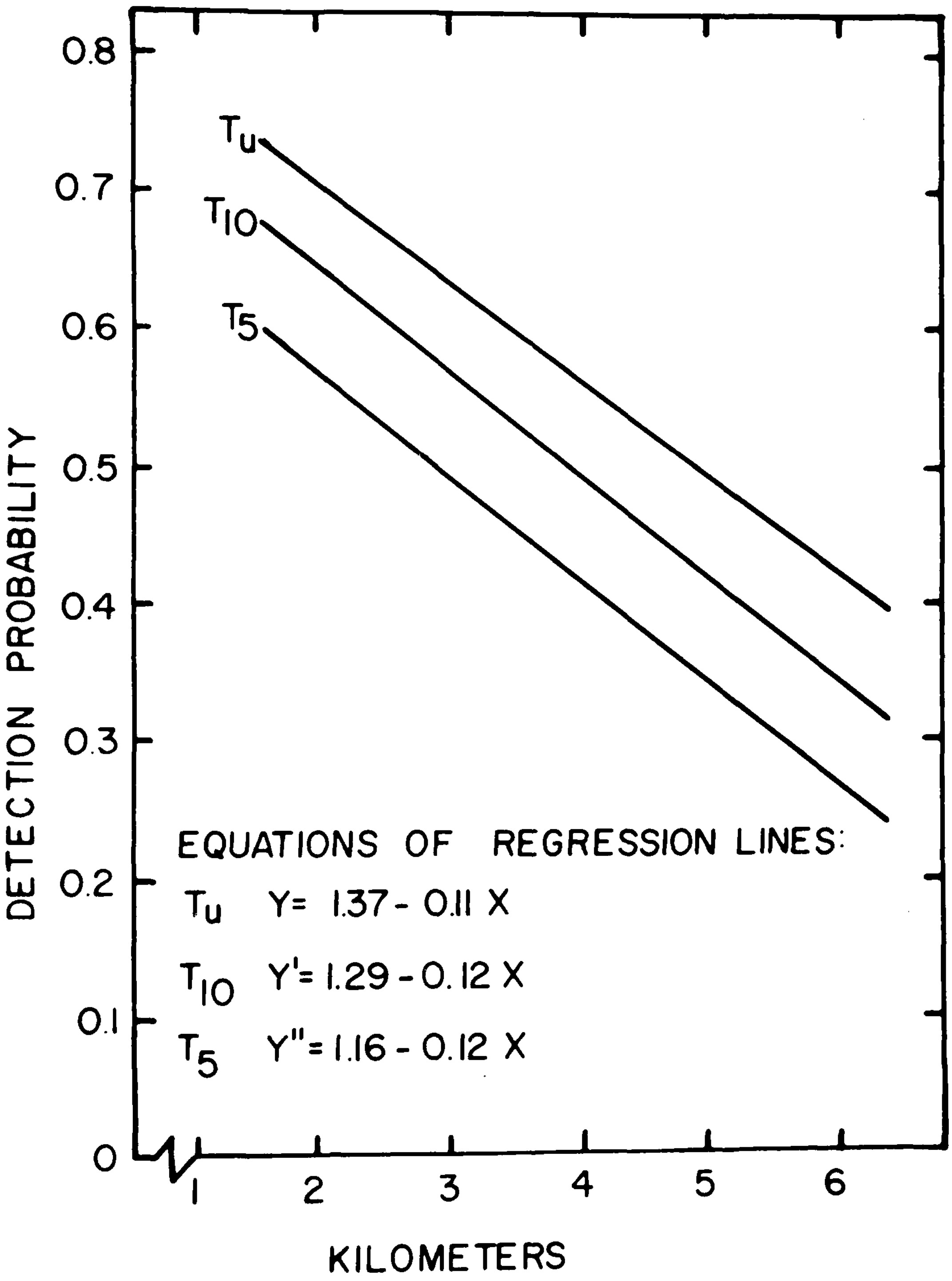

Figure 11. Regression lines showing effect of range on detection probability for paced and unpaced conditions (177).

Another set of nomographs is provided by Townsend and Mace (214) which shows the threshold sighting ranges for 95% probability of detection for both day and night conditions. Charts for two different size targets and contrast levels are given in Figures 14 through 19. These appear to be more applicable to the practical problem of observer confidence in having acquired the target. The Duntley nomographs, on the other hand, employ the 50% detection probabilities of the Blackwell data.

Glint

Another objective factor that may affect target acquisition is referred to as glint. Glint is a common everyday phenomenon which occurs whenever a light source is reflected off a specular surface in such a manner as to produce a focusing of the rays. Such a bright flash of light may in certain cases enhance detection by "catching one's eye," while at other times it may cause a temporary "blinding" of the observer with a subsequent degrading of detection capability. No quantitative data on glint effects are known to exist. Because it cannot largely be "created" nor controlled in the air-to-air search situation, it has apparently not been researched.

Observer Characteristics

Acuity

It is generally agreed that search time and search performance are dependent to a large degree on visual acuity. Grossman and Whitehurst (95) showed that subjects with better than 20/20 acuity located targets at least twice as fast as subjects with 20/40 or 20/50 acuity (Figure 20), implying that subjects with "normal" vision will perform better in a search situation. There has been demonstrated a low positive correlation ($r = 0.149$) between near-vision acuity and far-vision search performance (Johnston, 116).

Erickson (71, 72) showed that peripheral acuity correlates significantly ($r = -0.64$, $p < 0.01$) with search time: better peripheral acuity is associated with better (shorter) search times. Burg and Hulbert (44) said that peripheral acuity cannot be accurately predicted from static foveal acuity, and argued for the testing of peripheral acuity to determine search performance on the basis that better peripheral acuity would lead to an increased proportion of targets being detected without direct foveal viewing. This would, in turn, lead to correspondingly shorter search times.

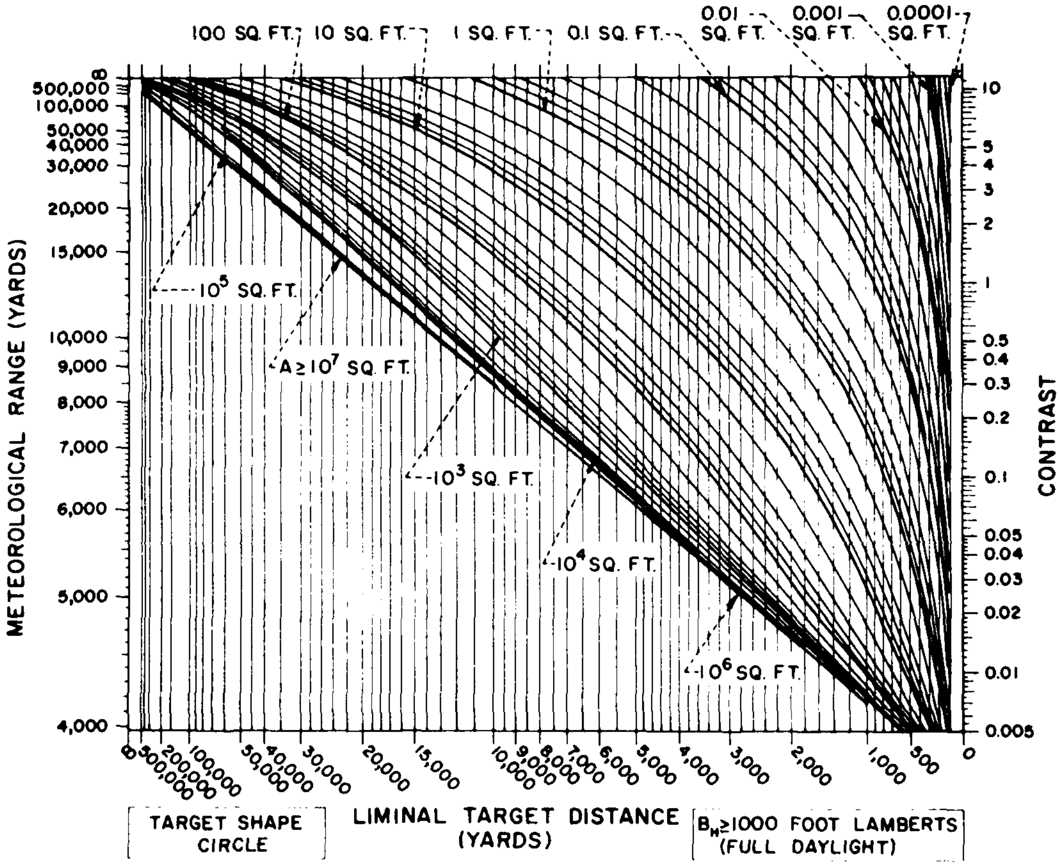

Figure 12. Nomograph for full daylight conditions (64, p. 239).

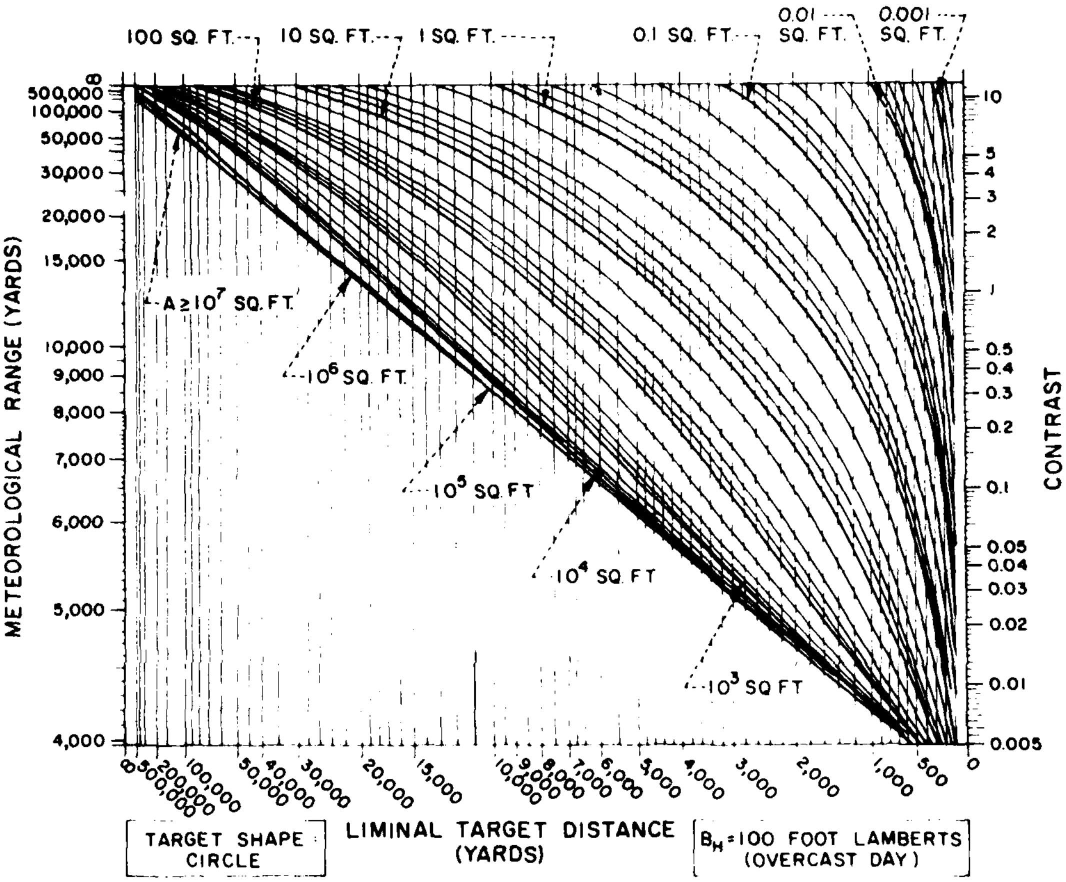

Figure 13. Nomograph for overcast conditions (64, p. 240).

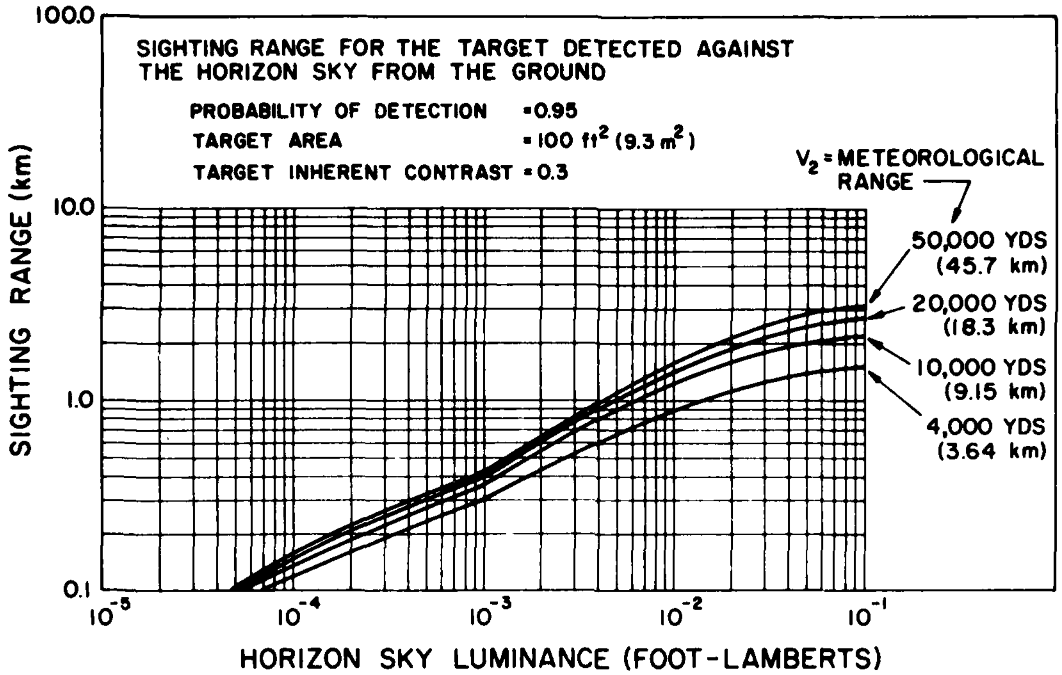

Figure 14. Sighting range for target detected against horizon sky from the ground (214).

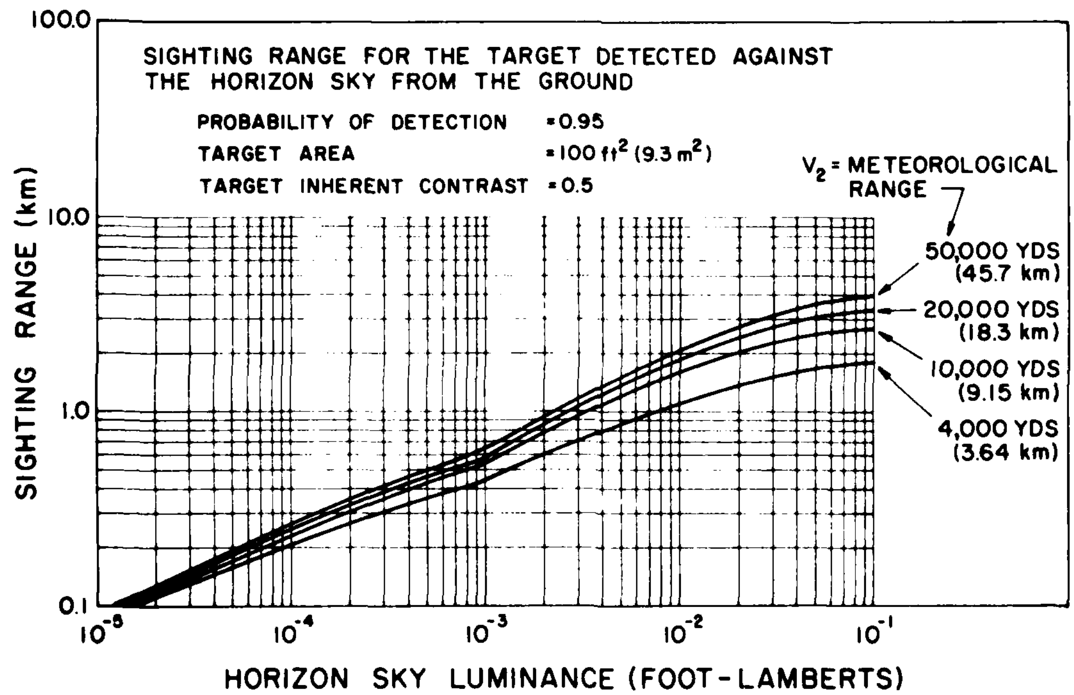

Figure 15. Sighting range for target detected against horizon sky from the ground (214).

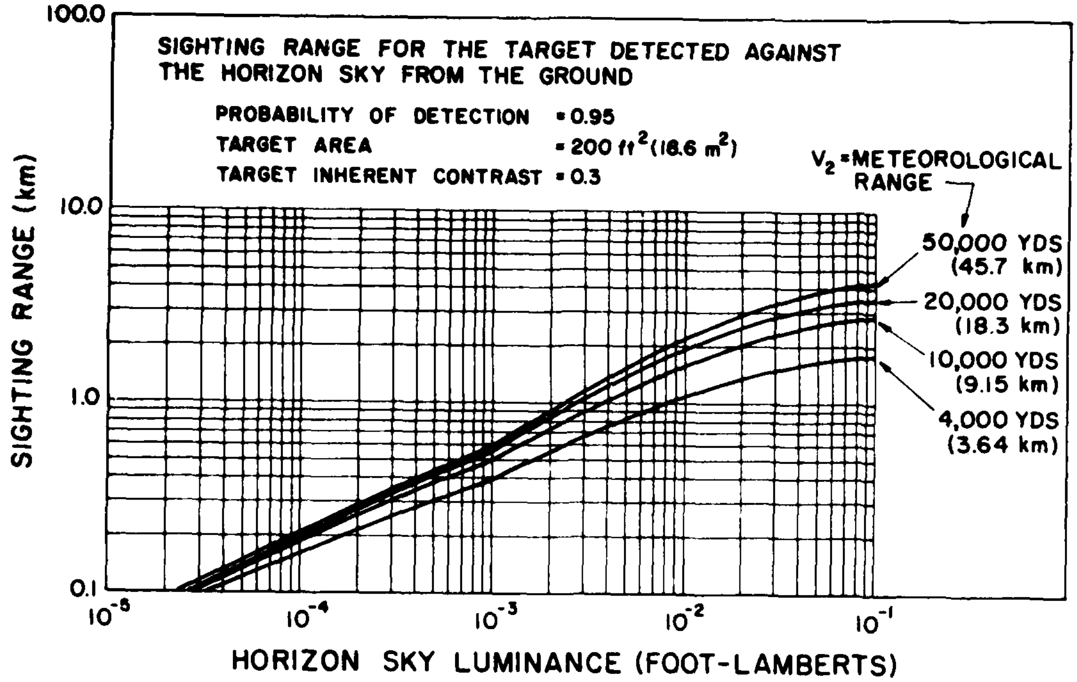

Figure 16. Sighting range for target detected against horizon sky from the ground (214).

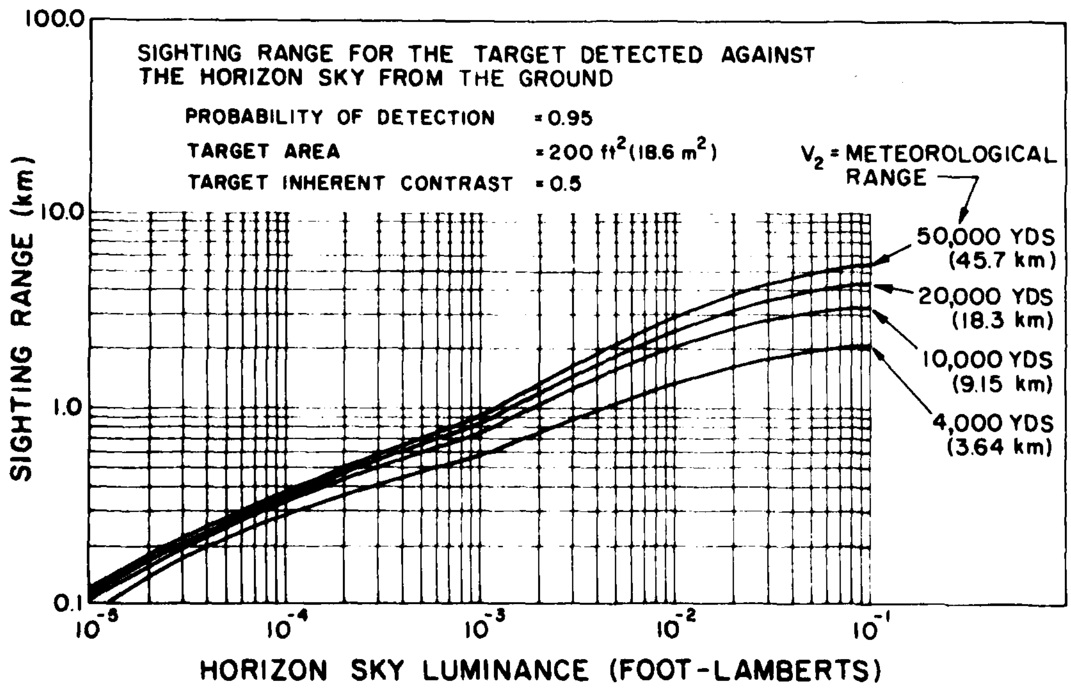

Figure 17. Sighting range for target detected against horizon sky from the ground (214).

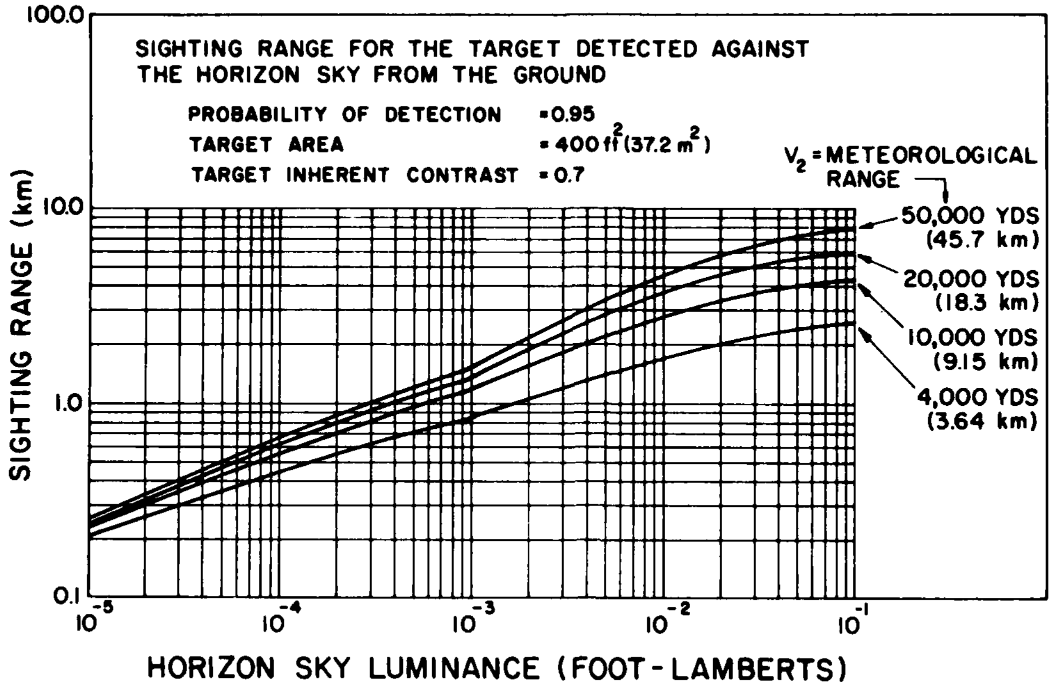

Figure 18. Sighting range for target detected against horizon sky from the ground (214).

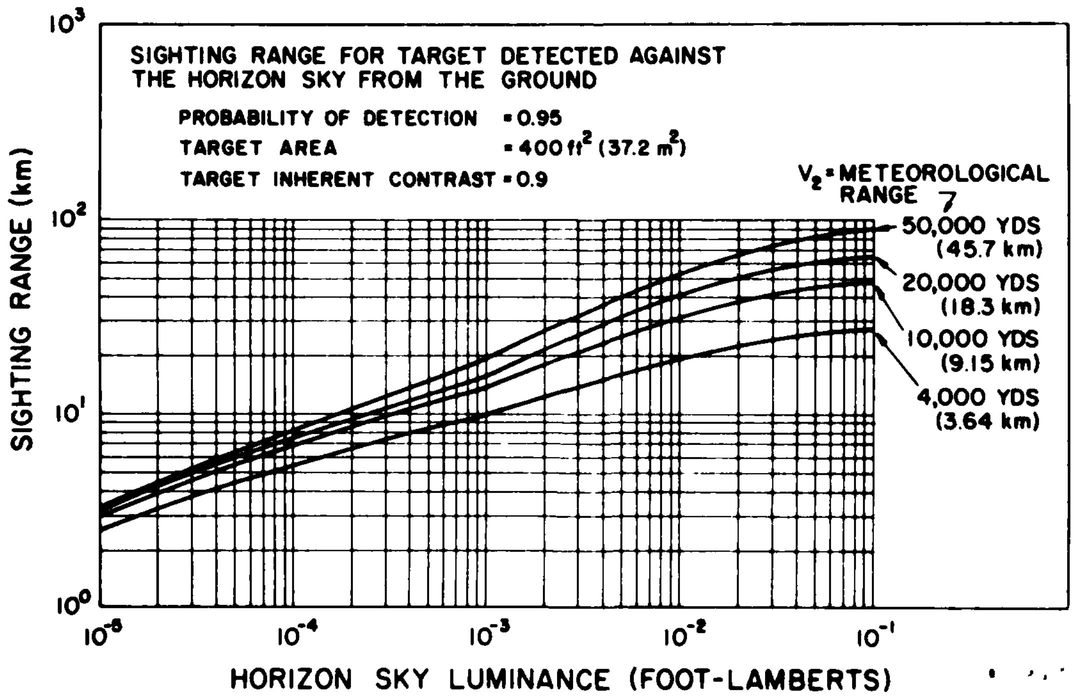

Figure 19. Sighting range for target detected against horizon sky from the ground (214).

It has been demonstrated that larger visual fields demonstrate shorter search times (Johnston, 114), but an individual's sensitivity to movement steadily decreases as a linear function of the distance from the fovea to the target image on the retina (McClogin, 153), perhaps indicating a cut-off point after which the size of the visual field makes no difference. Beyond this point, an observer's acuity or sensitivity may be so weak that no targets are detected, even though gross movement of large objects can be seen.

A number of authors (Miller, 158; Reading, 186; and others) have noted that acuity deteriorates markedly with increases in target velocity (Figures 21 and 22). Ludvigh and Miller (148) attribute this drop in acuity to movement of the image on the retina and the resulting loss of subjective contrast. Erickson (71) states that at higher target velocities, foveal acuity is a more important factor than peripheral acuity in search-type tasks. The better acuity of the fovea as compared to the periphery leads to shorter identification times. These high velocities require a more sensitive area of the retina for detection. This reasoning appears quite appropriate.

There seems to be general agreement that there exists a low positive correlation between static visual acuity and dynamic visual acuity (DVA) (Weissman and Freeburne, 222, and others). Burg and Hulbert (44) found a correlation of $r = 0.1798$, $p < 0.001$. However, Weissman and Freeburne (222) also noticed that this correlation disappears at higher target velocities, 150 deg/s and higher. Elkin (67) summarizes this effect by saying that good static acuity is a necessary but not sufficient condition for good DVA (i.e., in order to have good DVA, it is necessary to have good static acuity, but good static acuity does not necessarily lead to good DVA).

Miller and Ludvigh (164), in examining the effect of relative movement upon visual acuity, noted that a subject's acuity in a condition where the target is moving is approximately the same as in a condition where the subject himself is in motion (Figure 23). It should make no difference to the observer if the target appears to be moving, or if the observer himself appears to be moving with respect to the target. His DVA should remain the same.

There appear to be consistent and predictable age differences in acuity. Burg (43) noted that the size of the visual field of view (visual field) is at a maximum at roughly age 30, and the size of the field decreases after age 35. This finding was also noted by Low (146), who said that age does not alter the size of the visual field until after age 40.

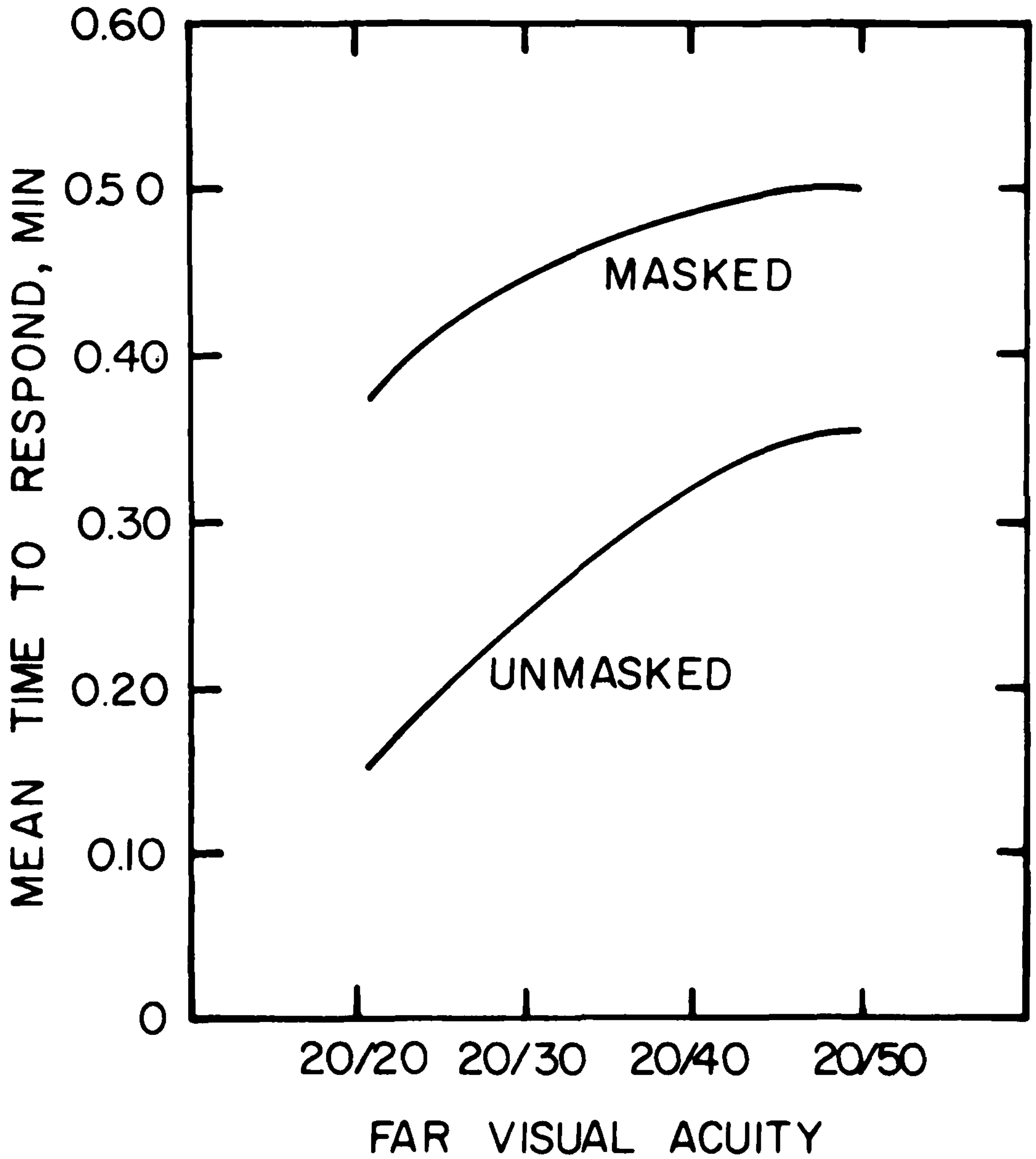

Figure 20. Mean search time as function of visual acuity and masking, data combined across range and subjects (95).

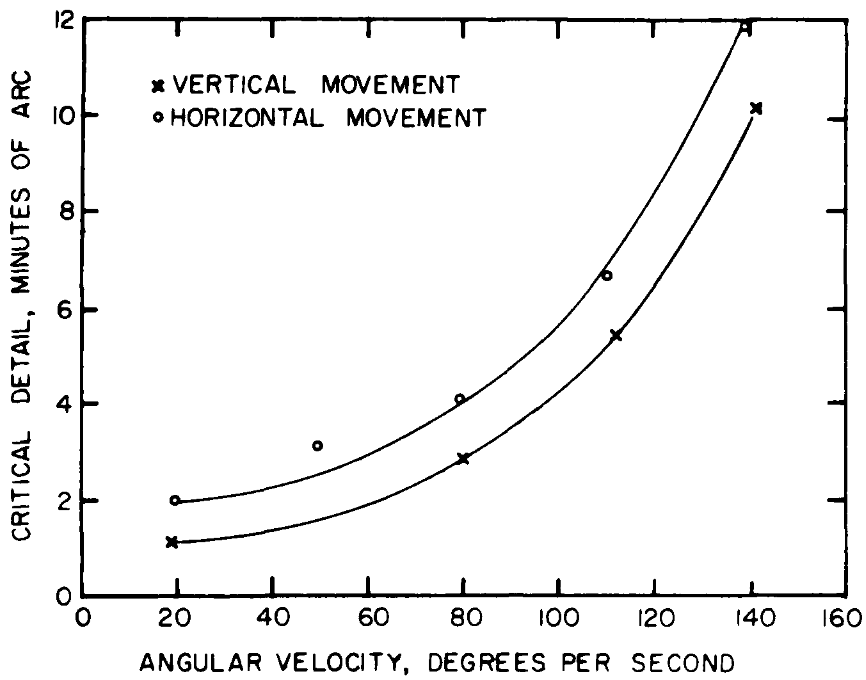

Figure 21. Mean dynamic visual acuity threshold values of 9 subjects obtained in horizontal and vertical planes of pursuit (158).

Burg (43) reported that females have slightly larger visual fields than do males, but sex was not found to be a significant factor in another experiment by Low (146). However, Low had a fairly restricted subject pool (100 subjects) as compared to Burg who used 17,300 in a rather rigorous experiment (Figure 24).

As for fatigue effects on visual acuity, Behar, Kimball, and Anderson (21) state that acuity decreases with fatigue, and intrasubject variability increases, especially at higher target velocities (Figure 25). The subjects in this study were allowed only 3-5 hours of sleep a night for five days. This very small amount of sleep may not present itself except during a heavy combat situation.

However, Davies and Tune (54) noted that a lookout's vigilance began to deteriorate almost as soon as he began his task, and reached a minimum after a few minutes. This could be due to the fatigue-inducing effects of vigilance tasks, and may indicate the need to continuously monitor an observer under visually impoverished conditions.

A number of investigators have examined the effect of practice on peripheral vision, and all have noted that peripheral vision improves with practice (Figure 26). The

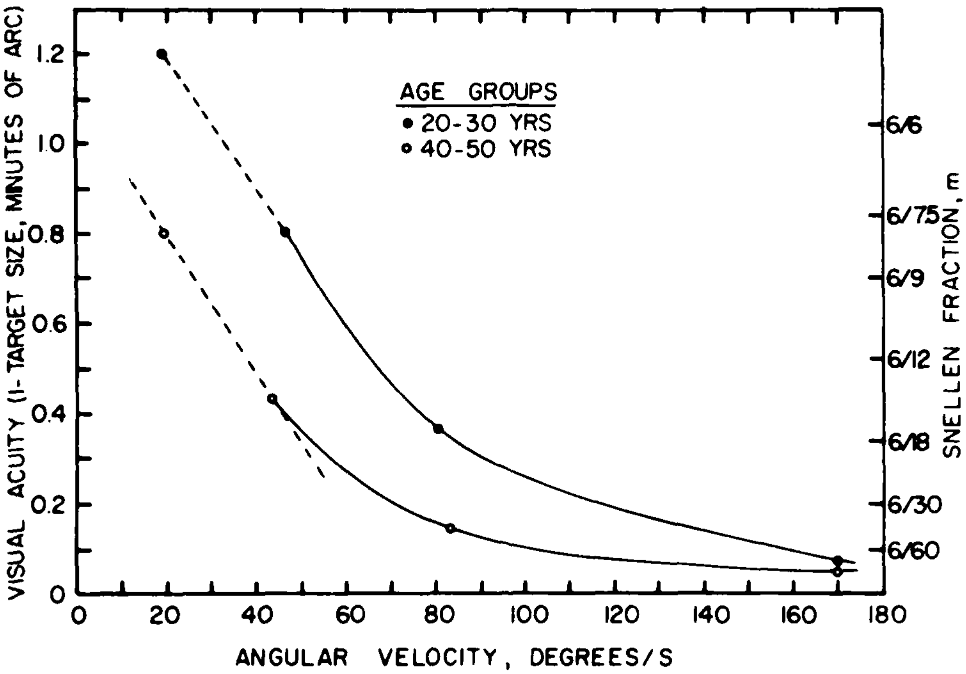

Figure 22. Dynamic visual acuity as function of speed of target movement (186).

diminution of the peripheral field with increased concentration can be alleviated with training (Leibowitz, 144). Erickson (72) noted as an aside that his subjects appeared to improve in peripheral visual acuity from session to session (Table 2). Low (146) showed that peripheral visual acuity can be improved with training, but this improvement is very slow. Its principal requirements are long continued practice, unlimited viewing time during practice, and stationary test objects.

It may be possible to improve peripheral static acuity with training, but it seems that it may take a good deal of time, which may limit the usefulness of such training in an applied setting. Another question, of course, is the generalization of such training to the flight environment.

It is generally agreed that DVA can be improved with practice (Behar et al., 21; Burg and Hulbert, 44; Miller and Ludvigh, 164). But there appear to be large individual differences. Miller and Ludvigh (164) report that DVA improves at a greater rate for higher target velocities, and if there is any improvement to be made at all in DVA, it occurs fairly rapidly (Figures 27 and 28).

There appears to be a leveling off of improvement in DVA with practice, which may indicate some limited usefulness of

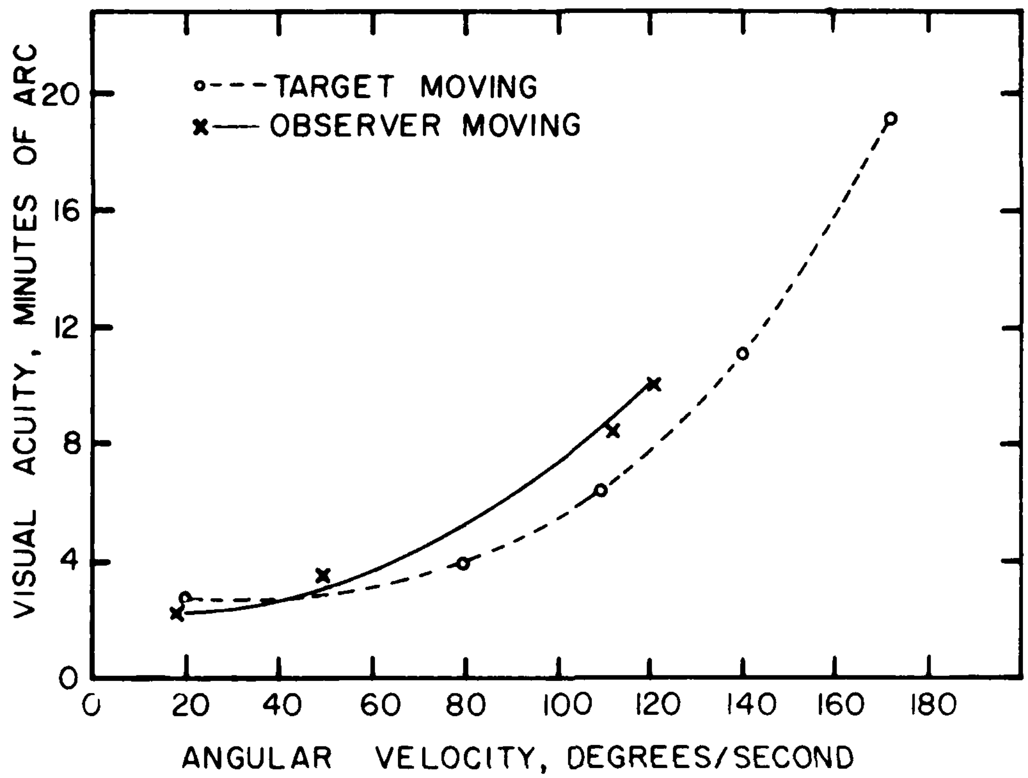

Figure 23. Comparison of visual acuity with test object moving versus observer moving (164, p. 93).

training. It seems that practice can improve DVA to a certain level; again, its generalization to the air-to-air search task must be demonstrated.

Accommodation and Myopia

More will be said in a later section about myopia and accommodation as a response to the search situation (especially the empty field), but it deserves a few general remarks here.

Whiteside (226, 227) and Brown (42) seem to be the first authors to examine myopia and accommodation as a problem encountered in flight. They also appear to be the first investigators to measure quantitatively accommodation in response to high altitude, empty-field conditions.

Whiteside (226) found that subjects cannot voluntarily relax accommodation to infinity, although they do exhibit a certain amount of voluntary control over accommodation, being able to obtain approximately a 1.7 diopter level.

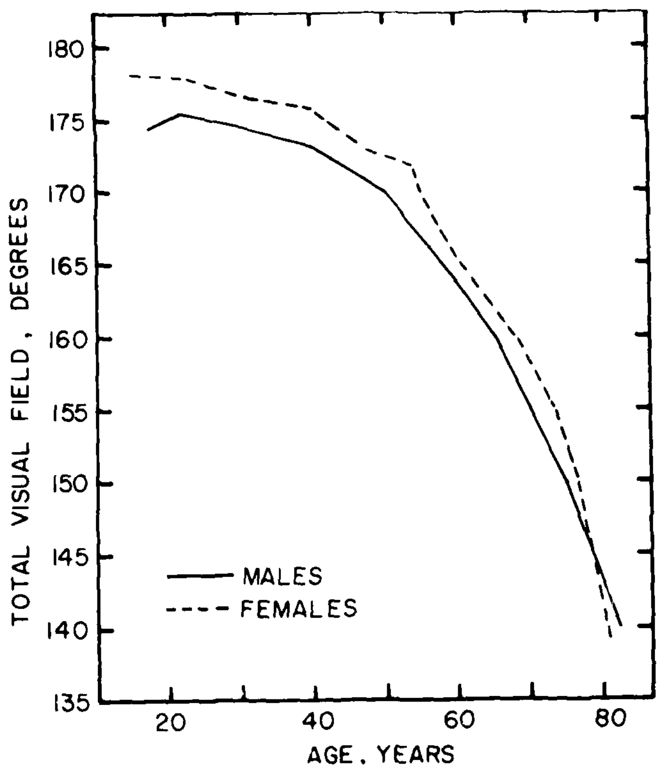

Figure 24. Total visual field by age and sex (43, p. 13).

In another study (Whiteside, 227), it was shown that the time required for accommodation to reach a resting level after the disappearance of structure from the field is roughly 60 s, whether this relaxation was voluntary or resisted by the subject.

The phenomenon of night myopia, as distinct from empty field myopia, was examined by Koomen, Scolnik, and Tousey (128). This first occurs at the luminance level where rod vision begins to predominate over cone vision, and the myopia grows larger as the luminance level is reduced further (Figure 29). They concluded that night myopia and its dependence upon the luminance level is primarily due to undercorrected spherical aberration of the eye. They showed that accommodation is not a significant factor in night myopia, as they were able to induce myopia when accommodation was prevented by drugs or by an optical method.

Smoking, it appears (Powell, 181), has a definite adverse effect upon the eye's ability to accommodate to varying distances. In summarizing a series of eight papers, Powell (181) noted that smoking first stimulated then depressed the function of accommodation. No data were given as to the amount smoked, nor were there any data over time given.

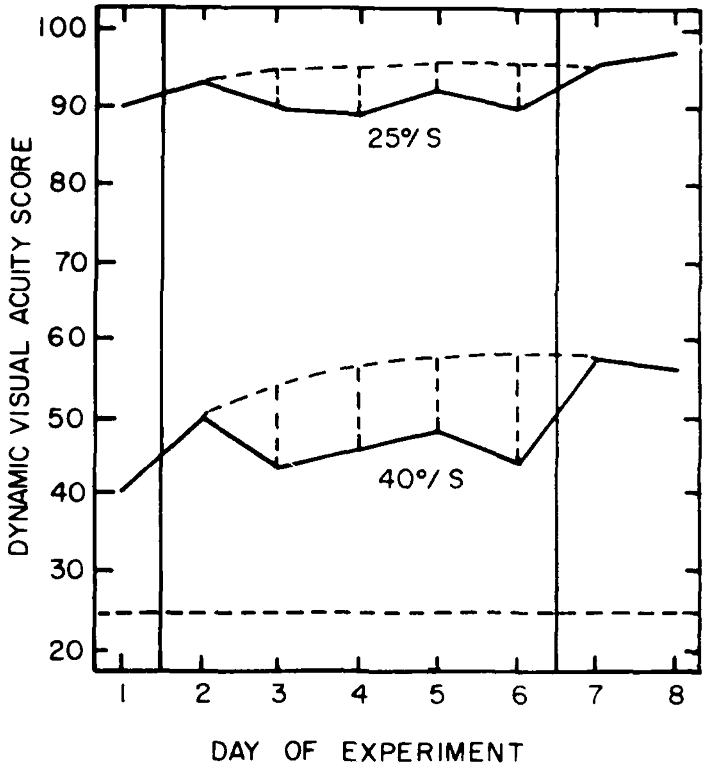

Figure 25. Variation, DVA mean scores over experimental days, and hypothetical practice functions expected in absence of fatigue (21).

Woodson and Conover (234) describe empty-field myopia as a condition in which the eyes tend to accommodate for a distance of about six meters in front of the observer. However, this "resting" distance varies from one observer to another.

Whiteside and Campbell (in Matthews et al., 156) define empty-field myopia as the condition in which an observer with normal eyesight performing a target acquisition task in a bright, textureless field is myopic by about 0.5 to 2.0 diopters. In examining the effect of accommodative aids (in the form of grids or dots projected over the search area), Matthews et al.(156) performance levels were 25%-30% lower with an empty field as opposed to performance with an accommodative aid. Auxiliary techniques to reduce the effects of empty field and night myopia will be discussed subsequently.

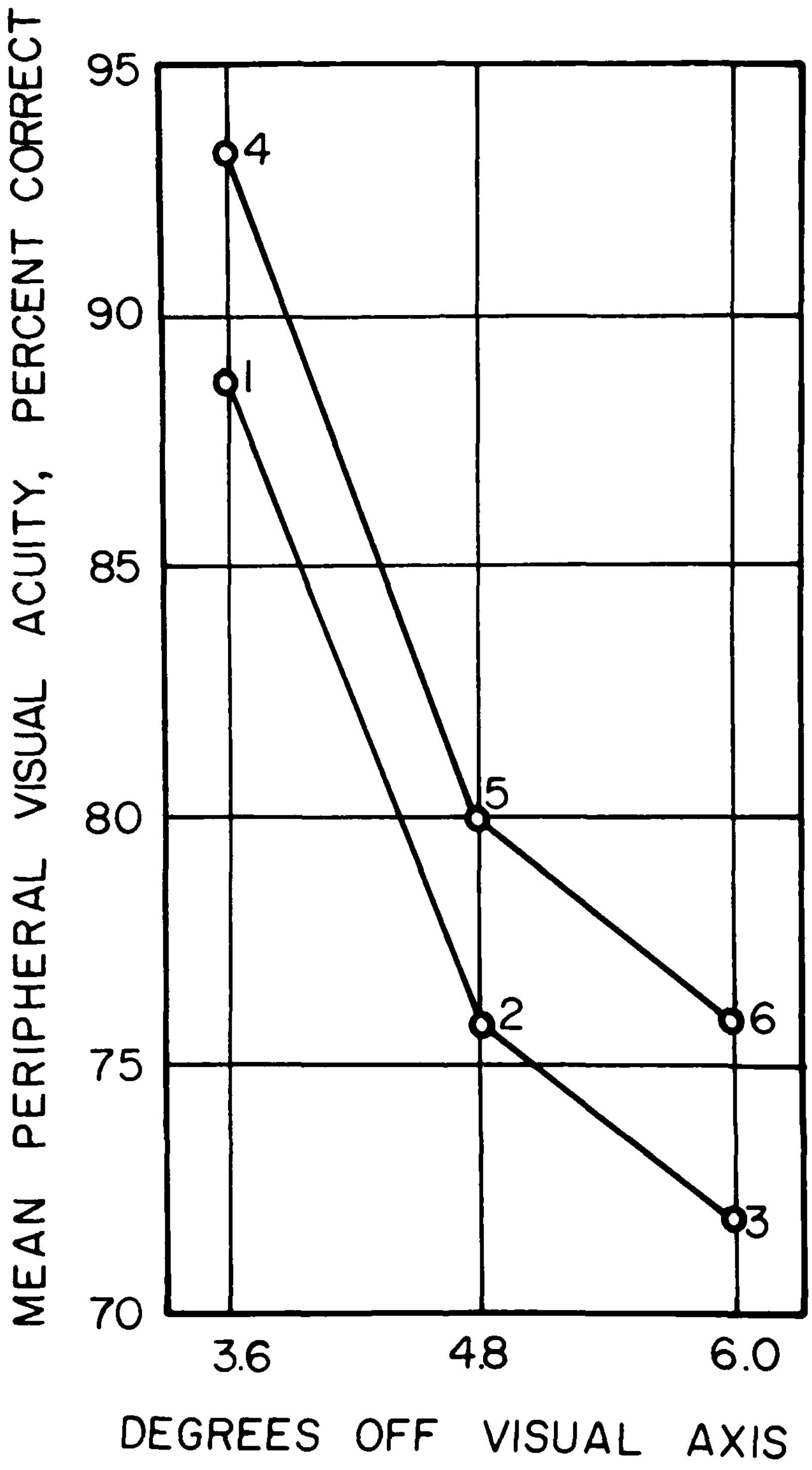

Figure 26. Mean peripheral acuity score from sessions 2 and 5 (71, p. 19).

TABLE 2. FOVEAL ACUITY, SEARCH TIME CORRELATIONS (72, p. 175)

Session Number	Foveal Acuity Score Right eye	Left eye	Best eye	Average
1	0.271	0.195	0.171	0.290
2	0.335	-0.016	-0.012	0.225
3	0.235	0.020	0.035	0.177
4	0.329	0.331	0.288	0.402
5	0.088	0.068	0.076	0.100
6	0.046	0.466	0.468	0.279
Average	0.303	0.192	0.184	0.313
Density, 16	0.470	0.407	0.443	0.541[a]
Density, 32	0.360	0.183	0.142	0.344
Density, 48	0.116	0.114	0.109	0.145

[a] Correlation is significant at the 0.05 level or better

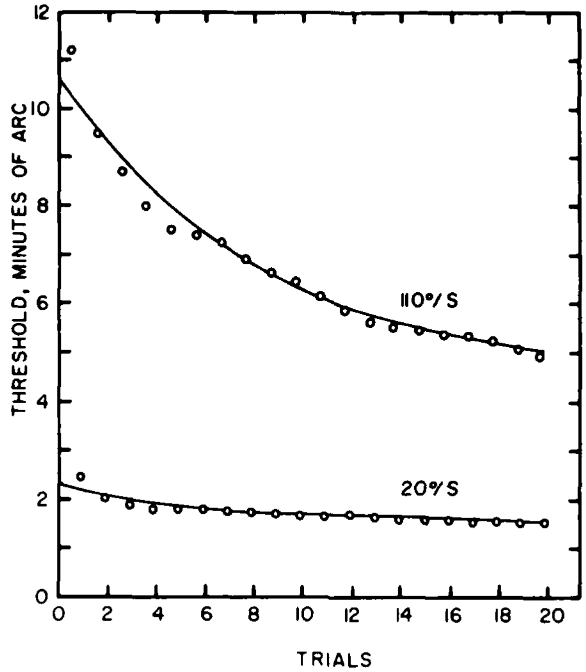

Figure 27. Effect of practice on dynamic visual acuity (164, p.102).

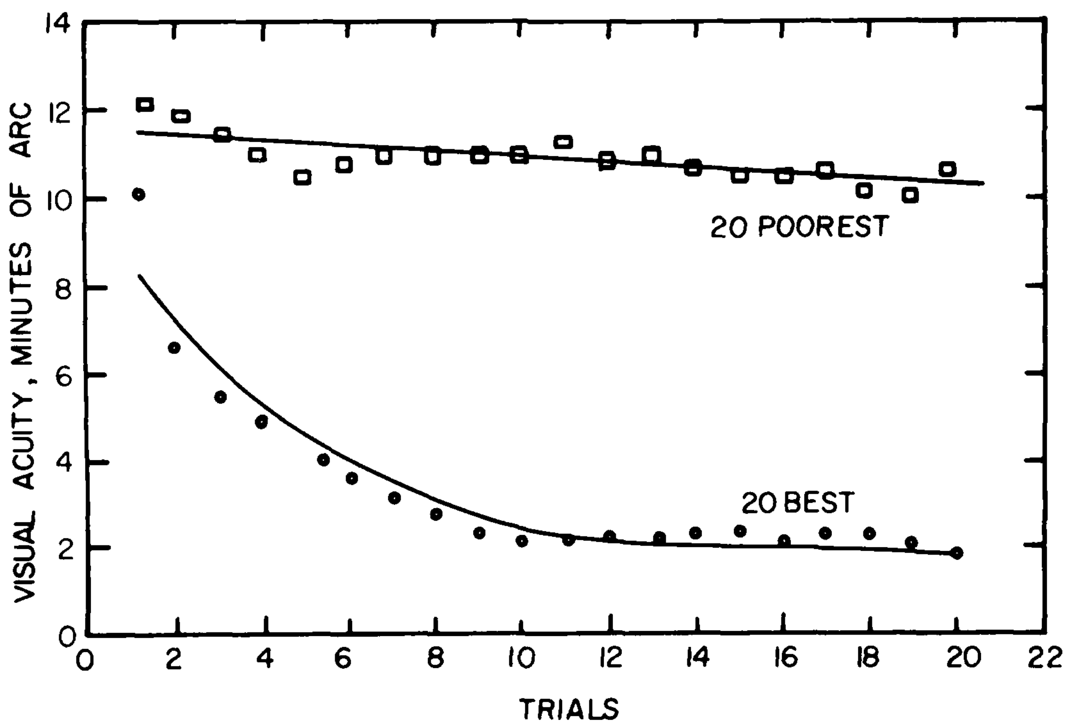

Figure 28. Mean threshold values of 20 poorest and 20 best performers (164, p. 102).

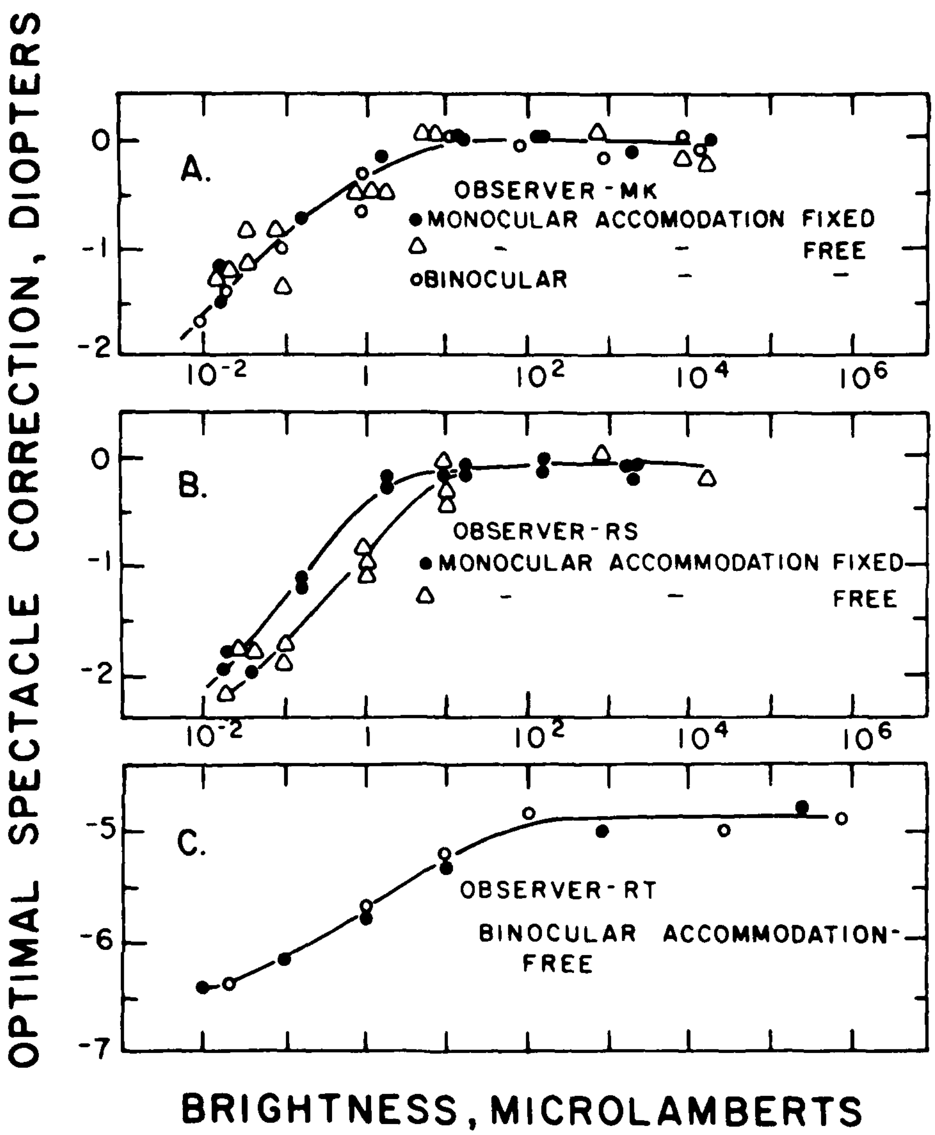

Figure 29. Night myopia versus luminance (128, p. 85).

Other Characteristics

Many other observer factors have been examined within the context of target acquisition. Motivation and/or the related incentive can have a positive effect upon search performance. Bahrick et al.(8) showed that a condition of high incentive facilitates the detection of stimuli presented peripherally.

Opposed to this, a lookout's vigilance begins to deteriorate almost as soon as he/she begins a search task (Davies and Tune, 54). Leibowitz (143) notes that peripheral detection decreases with increasing stress, and peripheral detection also decreases in severe vigilance tasks. This is attributed to the narrowing of the visual field due to high levels of concentration, a result also demonstrated by Gasson and Peters (83). They showed that the size of the binocular peripheral field decreases with increasing concentration on a central task. The percent shrinkage ranged from 6% to 46%.

Some sort of incentive is necessary to maintain performance in a search task, but this incentive should not place an unusual amount of stress on the observer, as it may lead to reduced peripheral detection rates.

Behar et al. (21) found that fatigue in pilots leads to an increase in the variability of dynamic visual acuity (Figure 25). These changes in acuity correlated only moderately, however, with the pilot's subjective estimate of fatigue intensity. This points to the need to use a more reliable device than pilot's self-evaluation to monitor fatigue intensity.

Smoking has been found not only to depress the accommodation function of the eye (178) but also to have a detrimental effect on search ability due to its adverse effects on peripheral acuity (113).

In examining transport accidents, primarily involving trains, Davis (58) found four conditions which lead to operators failing to see signal lights ahead of them in darkness: (1) low anxiety levels (especially after a period of high anxiety); (2) strong expectations about what is ahead; (3) the operator setting up a false hypothesis about the conditions to relieve anxiety; and (4) if one aspect of the task at hand requires a good deal of concentration, the operator will construct hypotheses about other aspects of this task. Davis implies that these conditions will lead the operator to see what he expects to see, not necessarily what is actually present.

Anxiety may often enhance the tendency to form hypotheses. A person can tolerate some uncertainty in a given situation when anxiety is at a low level. He or she may be able to wait for more information before taking action or adopting an hypothesis about what is occurring. However, if anxiety is aroused, one tends to adopt hypotheses about the situation on the basis of incomplete information and then act on those hypotheses.

Low anxiety levels after a period of high anxiety may lead to the creation of false hypotheses, as the subject may feel that the worst is over and may relax his/her attention.

Strong expectations about conditions may come from long experience in similar situations, situations in which he/she has made confident and correct appraisals. The operator may be alert for expected departures from normal operation. If he/she is not, he/she may misread, or fail to read, changes in the situation.

Two studies examined dynamic states of the cockpit and pilot performance (Besco, 23; White and Monty, 225). Both studies concluded that pilot performance on a tracking task decreases with the increase of unusual gravitational forces such as vertical accelerations (Figures 30 and 31).

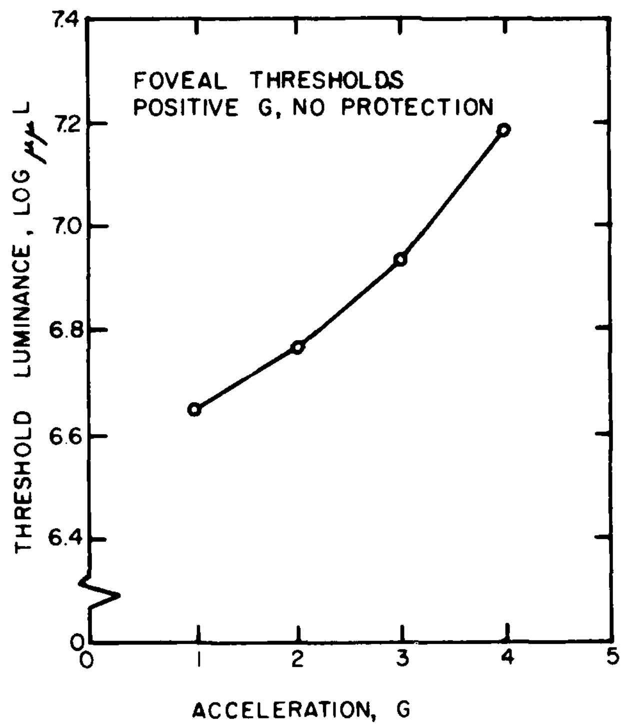

Figure 30. Foveal thresholds as a function of acceleration (225, p. 71).

Similarly, Clark (49) found that unusual vestibular stimulation leads to errors in the actual perception of the stimulus. During these periods of unusual vestibular stimulation (such as in steep dives, etc.), the only information that may be reliable is the fact that there is a target out there. Its exact position, however, may be erroneously perceived.

Davies and Tune (54) remarked that there was no substantial evidence of a relationship between intelligence and

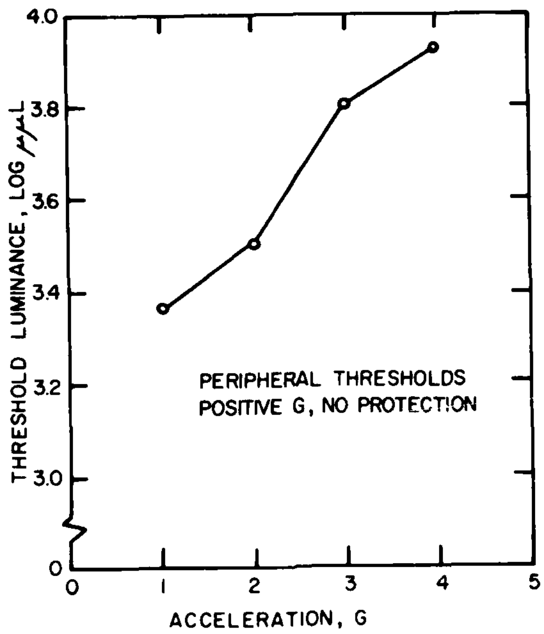

Figure 31. Peripheral thresholds as a function of acceleration (225, p. 71).

detection of targets. There exists some evidence that younger people perform better and there is no evidence supporting sex differences (even though acuity differences have been found). They note that extroverts make fewer correct detections than introverts, and they may show a greater decrement in performance with time on task.

There was a significant correlation ($r = 0.66$, $p < 0.001$; Thornton, Barrett, and Davis, 213) between perceptual style and the ability to correctly identify targets in aerial photographs. Perceptual style is a concept used to describe a continuum extending from field independence (high proficiency in pulling an item from an embedding context) to field dependence (lower proficiency in pulling an item from an embedding context). This has applicability in training for target detection. It is well-known that even with training, a wide range of individual differences exists in detection ability. Using the concept of perceptual style, it may be possible to tailor training to the individual to perhaps eliminate these differences. Conversely, aircrew selection based upon field dependency may be a criterion useful in achieving a greater target detection capability.

Monk (167) demonstrated a significant sequential effect in target acquisition. He noted that the time required to locate a target decreased significantly if the target on the previous trial was in the same place. This seems to imply that observers tend to search for targets first where a target has recently appeared (or typically appears). This would tend to produce a high probability of fixation in that portion of the visual field which would reduce the fixation rate in the rest of the field. To increase the probability of target detection over the entire field, one should avoid this sequential effect, perhaps through making the observers aware of the problem, or perhaps through training.

Search Situation

Response to an unstructured field. Pilots and observers in planes at high altitudes (especially 35,000 ft or higher) frequently report difficulties in the visual detection of other aircraft. The primary cause of this difficulty is the lack of structure and detail in the visual field.

This "empty field" state can lead to a disorientation of the observer. He cannot really be sure where he has already searched, nor where he has yet to search (156; 75). There is also very little feedback from the ocular muscles, leading the observer to be unsure of where the eyes are aimed without having some detail to fixate upon (Avant, 6). As a result of this, the observer may orient himself with respect to some sort of internal coordinate system that may not correspond to the coordinate system of the aircraft. This action may lead to two types of occurrences: (1) the observer may perceive a target which is straight ahead to be on a noncollision course and take no evasive action, and (2) the observer may perceive a target which is on a noncollision course to be on a collision course and may take excessive or inappropriate evasive maneuvers.

Avant (6) reported that prolonged exposure to a homogeneous (i.e., empty) visual field may lead to a failure of the perceptual mechanism: an actual temporary cessation of vision. This state was immediately terminated with the injection of figures into the empty field, even if the figures could not be identified. In a situation where an observer is informed by some other means of the presence of a target in a homogeneous visual field, lengthy search may lead to such a failure of the visual system. This could be remedied by having the observers repeatedly glance at instruments or some other detail of the aircraft to terminate this failure.

Observers report a number of subjective responses to exposure to an empty field. Some report a sensation of being immersed in a "sea of light" (Avant, 1965). As the illumination increased, the observers noted that the fog condensed into a regular curved surface which surrounded the observer on all sides. With further increases in illumination, the surface flattened out into a plane. This tendency may lead to problems in depth perception and errors in estimating the range to targets detected.

Other observers have noted an apparent persistence of motion of objects seen in an otherwise empty visual field (Cohen, 50; Miller and Ludvigh, 163). A spontaneous autokinetic effect has been observed with a stationary stimulus in an empty field (Cohen, 50, 51; Miller and Ludvigh, 161). This may present difficulties when there is no relative motion between the target and the observer. The observer may perceive the target as moving with respect to the observer himself when in fact it is not, resulting in erroneous perception of danger, or erroneous evasive action.

Miller and Ludvigh (161) also report the disappearance of targets while being fixated by an observer in a homogeneous field. They believe that accommodation mechanisms are not responsible but do not suggest any possible causes.

Another difficulty encountered in the empty field is that of empty field myopia (see the section "Accommodation and Myopia"). In the absence of structure, the eye generally "relaxes" its accommodation to a point about six meters in front of the observer. This relaxation is involuntary and leads to many problems in target detection. It takes less than one minute for this to occur, causing problems in acquisition very soon after encountering empty field conditions.

Targets may suddenly "jump into focus" at a position much closer to the observer than their detection range under normal conditions. This leaves little, if any, time for evasive action should it be necessary.

Response in a Congested Field. In a congested field situation, the difficulty in target detection lies in the necessity of having to pick the target out of "noise." Baker et al. (12) reported that both search time and error rate increased as a function of the number of irrelevant forms on the complex display. The same result was noted by Erickson (72): Search performance decreased when object density was increased (Figure 32).

This relationship would present problems where air traffic is fairly dense, such as near airports and in well-used paths, or when viewing aircraft from above a ground "background." The problem is not one of detection in this instance but rather identification of the criterion target among a number of nontargets.

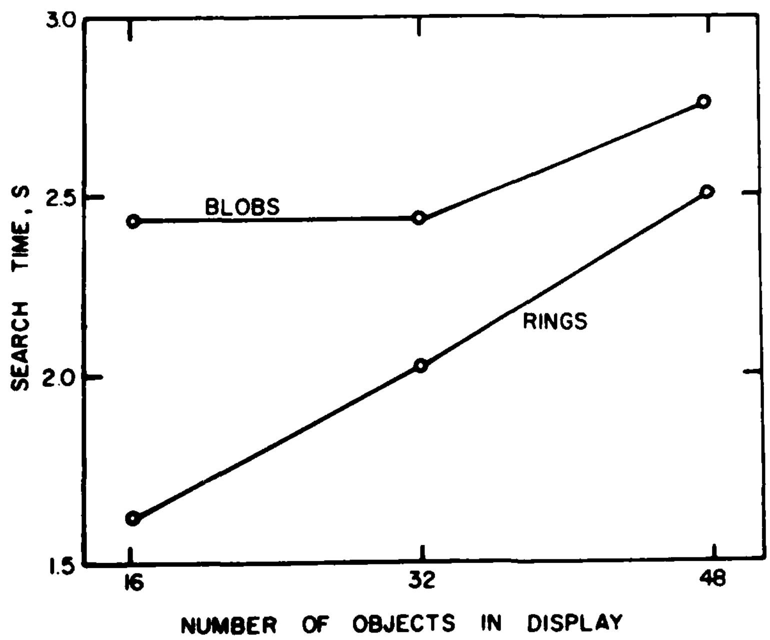

Figure 32. Search time for blob and ring displays of various object density (72, p. 170).

Enoch (68, 69) reports that there is a tendency for the number of fixations to increase the closer one gets to the center of the field, and a target is more likely to be detected the closer it is to the center of the visual field. In contrast to this, Baker et al. (12) and Erickson (71) report that targets located midway between the center of the field and the periphery were most quickly found (Figure 33).

The problem in the congested field, it seems, is the opposite of that in the empty field. In the empty field, there is too little to see, whereas in the congested field, there is too much to see. In the empty field, the visual signal-to-noise ratio is low because there is too little signal; in the congested field, it is low because there is too much noise.

<u>Competing Tasks of Pilot/Observer</u>. According to Wierwille and Williges (229), very little is known about the quantitative effects of operator workload upon visual detection, or visual performance in general. The only slightly related study is one by Bate and Self (19) that used a simulated side-looking radar display. By randomly blanking the display 0, 25%, 50%, or 75% of the time, they determined that ground target detection decreased and false alarm rate increased significantly with increased blanking. Clearly,

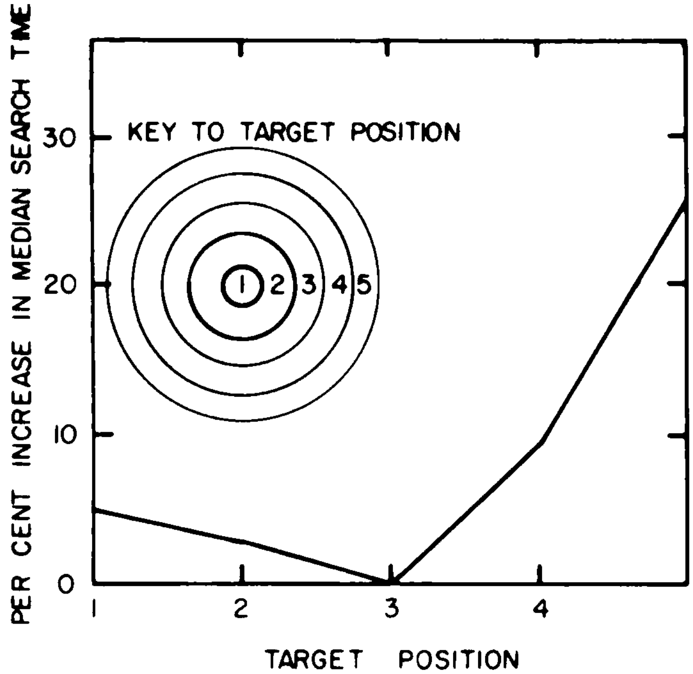

Figure 33. Search time as function of radial position of target on problem display (12, p. 58).

greater time sharing with other activities will probably detract from an air-to-air search task; however, quantitative relationships have yet to be determined empirically.

Eye Movements

One of the most noteworthy studies pertaining to the nature of eye movements was conducted by Ford et al. (79), in which eyeball movements were plotted from corneo-retinal potentials by the technique of electro-oculography. Some of the major results that are discussed in the section on "Modeling" deal with the duration of each fixation and the extent of angular movement between fixations. This movement of the eyeball between periods of fixation is referred to as saccadic motion, and it is so rapid in comparison to the time spent in fixations to be often considered negligible. Ford et al. (79) report, however, that saccades may comprise as much as 15% of the time spent during search. The basic results of this study are presented graphically in Figures 34, 35, and 36, showing the frequency distribution, average fixation time, and average angular travel during saccades, respectively.

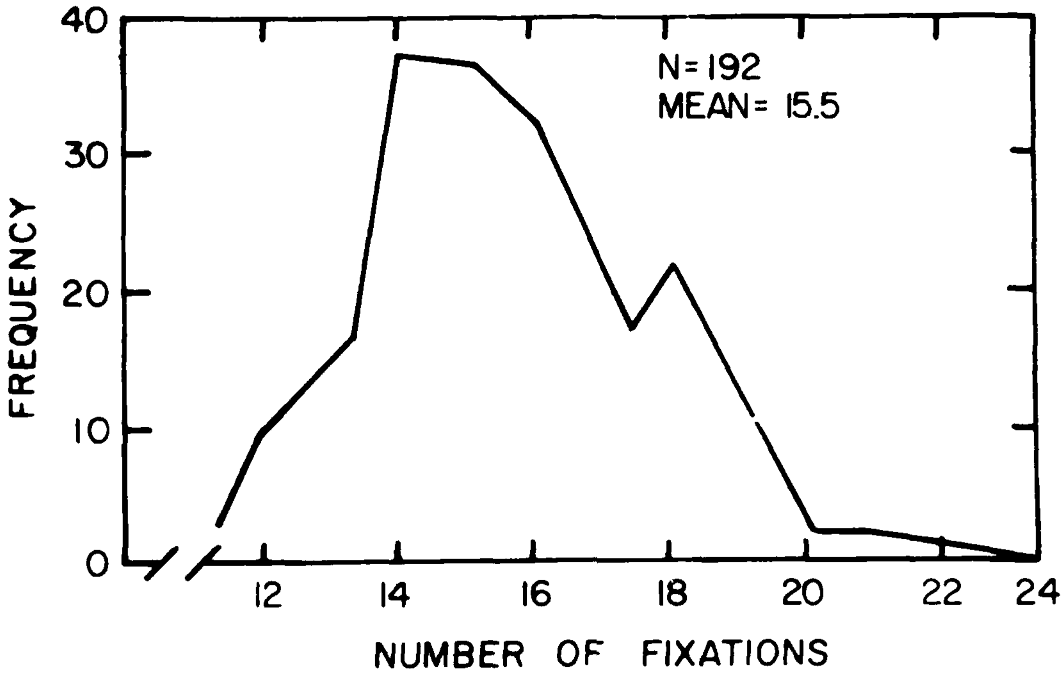

Figure 34. Frequency distribution of number of fixations made during 5-s search periods (79, p. 290).

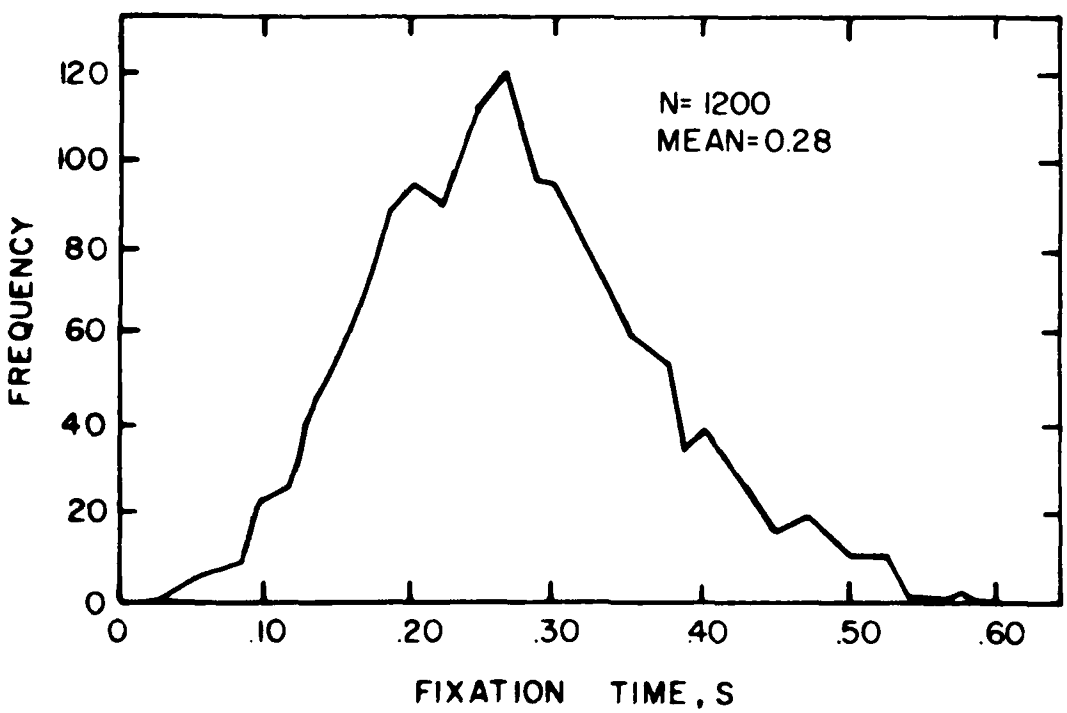

Figure 35. Frequency distribution of fixation durations for sample of 1200 fixations (79, p. 291).

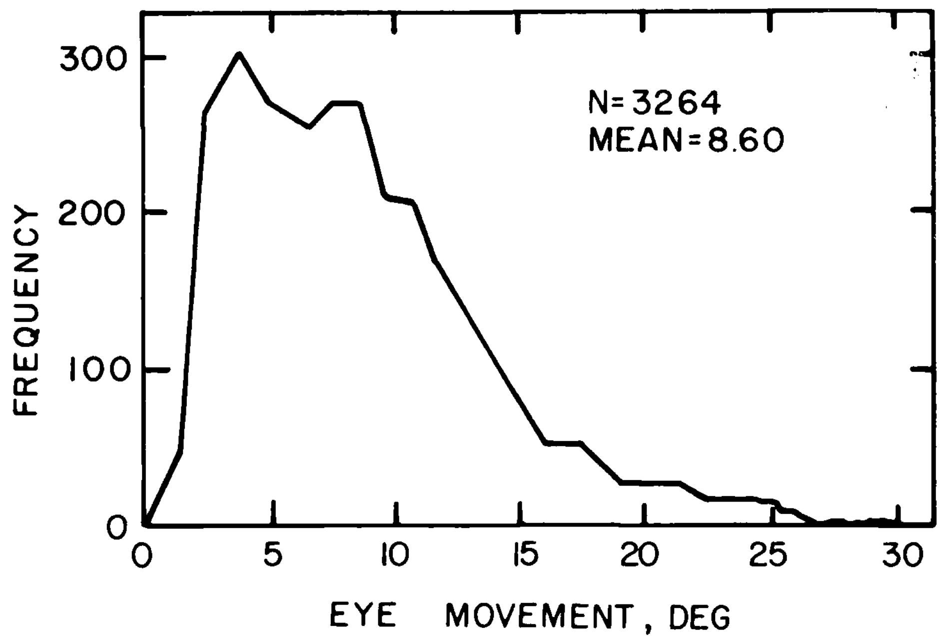

Figure 36. Frequency distribution of distances between successive fixations, in terms of visual angle (79, p. 291).

Almost all of the knowledge-gathering function of the eye occurs during fixations. Saccadic motion, in a sense, is the vehicle which determines where the next fixation will occur. Ford et al. (79) found that the pathway of eye movements is seldom straight. Moreover, it was determined that even when subjects were allowed to search "freely," there was a definite pattern, or spatial distribution of fixation, which was similar for the eye movement of all six subjects. It was suggested that the exact configuration of such uneven distributions may be determined by the size and shape of the field. It was proposed that the duration of fixations may be longer when the field being scanned contains complex or unfamiliar material.

Enoch (68) found that either trained or untrained subjects, when viewing aerial photographs, initially utilize a characteristic pattern of eye movement which is repeated with a high degree of similarity by the same individual. He calls this the individual's basic search pattern. (Noton and Stark (173) have renamed this same consistency "scanpaths.") This basic pattern will become more "specific" when some sort of a clue or cue as to the potential target location is provided. Without such cues, the observer will tend to expand upon or repeat the initial pattern.

However, Luria et al. (149) report that subjects did not exhibit a reliable pattern of scanning during search of a coded array of dials; two subjects did employ a systematic pattern when searching an embedded array. These reports should perhaps be regarded with reserve since only four subjects participated in the study. Their conclusion that systematic or random scanning is a function of conditions seems, nonetheless, to be valid.

In another similar study, Enoch (68) found that as the size of the display increased, the duration of fixations decreased while the interfixation distance increased (Figures 37 and 38). It was also reported that coverage of the display area was not uniform; there was a tendency to favor the center, right-hand side, and bottom of the display, while the upper left-hand corner was generally neglected.

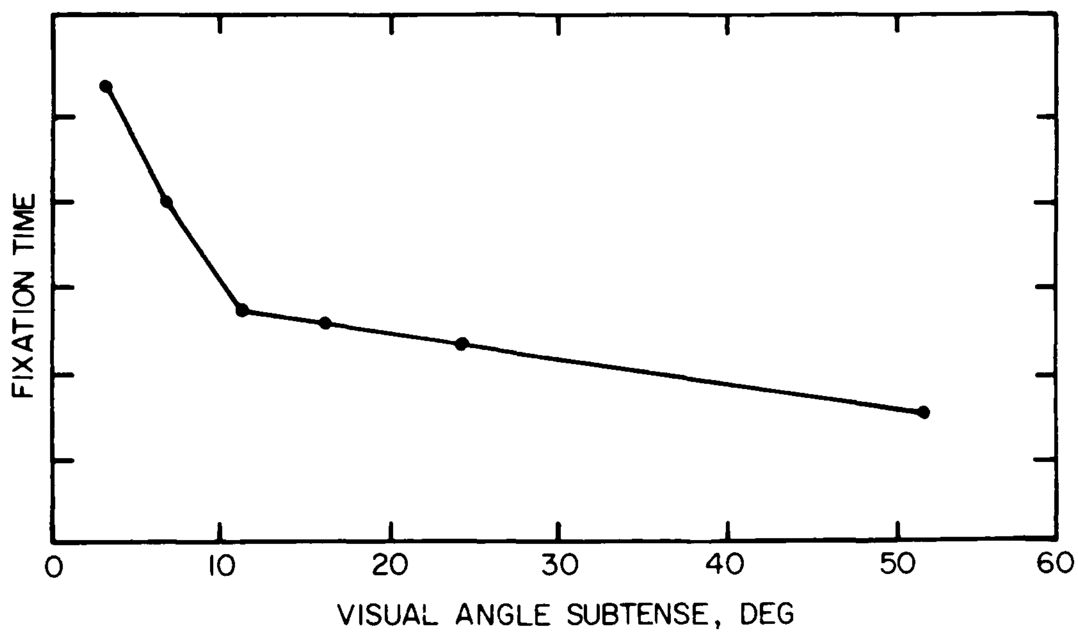

Figure 37. Average duration of fixation as function of angular subtense of display (68).

The issue of vision during saccadic eye movements was addressed by Volkmann (217). An experiment was conducted in which eye movements were recorded by a corneal reflection technique, and measures were taken to minimize blur while maintaining foveal stimulation. It was found that although vision was reduced during eye movements, visual detection is

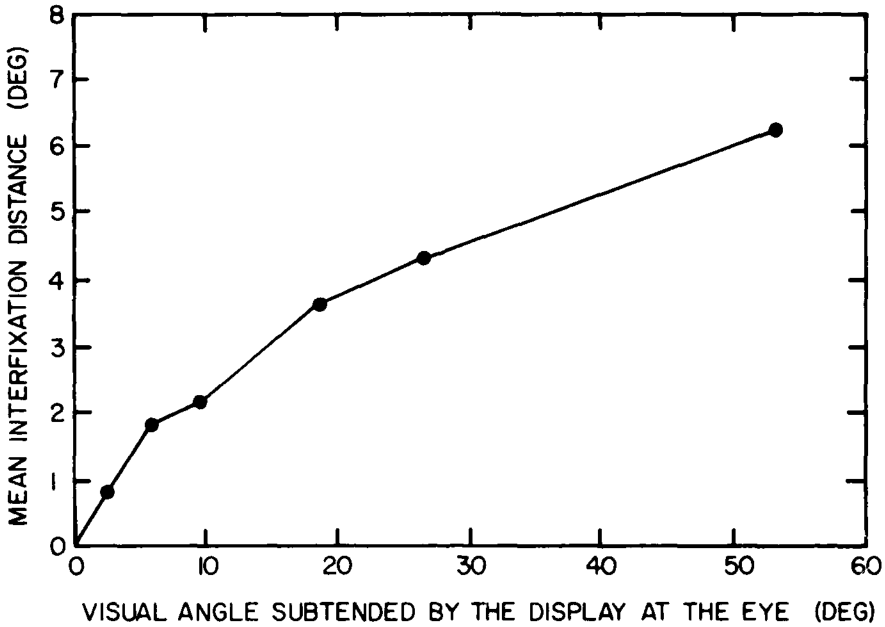

Figure 38. Average interfixation distance as function of angular subtense of a display (68).

possible during saccades. The moving eye thus required a stimulus flash about 0.5 log unit greater than the fixating eye for detection to occur.

In addition to voluntary saccadic motion, the human eye is capable of constant velocity following movements which are an involuntary response to the perception of movement. Westheimer (223) reports that as a subject becomes familiar with a target's rate of movement, an adjustment takes place which allows that target to be tracked smoothly, eliminating reaction times associated with saccadic motion. Such adjustments are referred to as psycho-optical reflexes.

Search/Scanning Patterns

Very little research has been done to evaluate the effectiveness of alternate search strategies, or scan patterns, upon target detection performance. While we know of no controlled air-to-air data, one extensive program for air-to-ground search produced some results worth noting. This program, called Task OBSERVE, was initiated in late 1957 by the U.S. Army Aviation Human Research Unit at Ft. Rucker, Alabama. It continued through 1964.

As part of this program, various personnel skills and training programs were evaluated in terms of their relationship to air-to-ground target detection. Of particular interest is an experiment comparing four search procedures:

1. Forward Fixed, in which the observer looked forward at an angle of 45 deg to the line of flight and downward toward tne terrain with his head held in a fixed position;

2. Forward Movement, in which the observer looked forward at a 45 deg angle to the line of flight initially, and then swept his gaze back toward the rear of the aircraft. The head was moved continuously to provide successive sweeps from fore to aft of the line of sight;

3. Side Fixed, where the line of sight was directed at 90 deg to the line of flight and downward; and

4. Side Movement, where the line of sight was 90 deg to the line of flight, and the observer swept his gaze inward toward the aircraft and outward toward the horizon. Head movement, rather than eye movement, was stressed.

The results of the field experiment indicated that the Side Movement method was consistently more effective than the other three methods ($p < 0.05$). The Forward Movement method was next best. It would appear that a moving, systematic scan pattern is better than any fixed direction, "push broom" coverage (Thomas and Caro, 212). Admittedly, the application of these results to the air-to-air task is tenuous.

Eye Movement Measurement Techniques

It is beyond the purpose of this report to examine critically the various means by which eye movement measurement can be made. However, because it may become desirable to monitor eye movements in a real or simulated air-to-air search situation, and perhaps even to train such search performance in a closed-loop fashion, some mention of alternate techniques seems desirable.

Young and Sheena (235) surveyed the various eye movement recording methods. Although some improvements have been implemented since the date of this paper, the state of the art has largely remained unchanged. The key methods are briefly noted below, along with estimates of their accuracies.

1. Electro-oculography. The position of the eye is measured by placing skin electrodes around the eye and measuring potential differences due to the corneoretinal potential, with sensitivities on the order of 20 mV/degree. Gross readings can easily be obtained with noise filtering time constants of about 3 seconds. The method is useful for wide fields, to +/- 70 deg. Linearity becomes progressively worse beyond 30 deg. Accuracy is on the order of +/- 1.5 to 2 deg.

2. Corneal reflection. The image (first Purkinje image) formed by the front of the cornea is measured as the eye rotates and (slightly) translates. Recording is usually photographic, but can be done electrooptically. The uncorrected linear range of this technique is about +/- 12-15 deg. Larger excursions are measurable but are nonlinear. Accuracy is 0.5-1 deg. Measurement can be done remotely, even surreptitiously. Head movement is possible, especially with a tracking system or a head mounted camera.

3. Limbus tracking. The sharp boundary between the iris and the sclera can be tracked electrooptically by several available techniques, much as systems track the corneal reflection. Because of lid occlusion of the top of the iris, vertical tracking is limited. Otherwise, accuracies are of the same order as the corneal reflection technique.

4. Contact lens method. Various techniques have been developed to affix devices tightly to the eye; these range from suction cups to contact lenses with stalks mounted on them. Tight fit and lack of slip are critical. Even with the best devices, the eye's acceleration during a saccade, often reaching 40 g, may cause significant recording error. Proponents of contact lens systems claim accuracies of 5-10 arcseconds, but only over a range of 5 deg. There are also substantial dangers resulting from fitting a contact lens with negative corneal pressure. Corneal deformation and damage to accommodation muscles are often cited.

5. Double Purkinje image method. Images formed by the front of the cornea (first Purkinje) and the rear of the lens (fourth Purkinje image) are coplanar between the lens and the cornea. The vector between these two images is tracked electrooptically. While head (or eye) travel is limited, and a bite bar is required with present

instruments, this method is accurate to about 2 arcminutes over a +/- 30 deg field. It is inherently linear, and has a bandwidth of 300 Hz, far in excess of other techniques.

6. Head position measurement. If free head position is required, then one may choose to measure separately the head angular position and the eye's position relative to the head. These geometric data can then be combined to offer eye line of sight in three-dimensional cockpit space, for example. Systems exist to permit such measurement over +/- 75 deg about each axis, with close to +/- 1 deg accuracy.

The reader is referred to Young and Sheena (235) for a more detailed review of these alternative methods.

Modeling

Issues and Purposes

The foregoing discussion has been directed toward outlining the pertinent variables and conditions involved in the act of target acquisition. As has been pointed out, detection is dependent on the complex interaction of a large number of observer, target, and environmental parameters. Based on the results of laboratory research and operational and field experiment data, combined with a knowledge of the physical properties of light through the atmosphere, numerous attempts have been made to describe this process with a mathematical model.

Physical Description. One of the primary purposes of a model is to provide a physical description in mathematical terms of the event or process of interest. In this context, one is concerned with the process of search and the event of acquisition, or detection. In general, a model should include in its formulation those parameters that significantly enter into specifying the desired outcome. Since there are numerous physical and psychological variables involved in air-to-air target acquisition, the problem becomes not only one of correctly depicting what is included in the model but also one of excluding those variables that are inconsequential.

Those parameters generally agreed upon to be included in the models are those describing the objective scene such as field luminance, target contrast, target size and its associated range (determining apparent size or angular subtense at the eye), angular displacement from the line of sight, target and observer velocity, and atmospheric conditions.

Assumptions are generally made, however, when describing the internal processes of the searching observer. These usually include the concept of an "ideal observer," one whose motivational or fatigue-related variables can be ignored, and one who searches vigilantly with an optimal strategy geared to specific flight situations and conditions. In a sense, then, such models are "ideal" models, rather than "normative" (or typical performance) models. The types of assumed search strategies and corresponding mathematical descriptions for search in both structured and unstructured (empty) fields will be treated below.

Prediction of detectability. Once a model has been set up to presumably describe the air-to-air acquisition task, it is generally called upon to assist in the prediction of target detectability by furnishing performance estimates as outputs, such as the maximum range at which one could detect a given size target under specified environmental conditions, the probability of detecting the target in a single glimpse, or a cumulative probability of detection as a function of time or range.

The model inputs, such as contrast, size, and position, must be derived from existing data bases which include the results of psychophysical experiments as well as flight tests and operational data.

Problems in data collection. In a review of the problem of air-to-air visual search, Erickson and Burge (76) warn of the "hazards in modeling visual performance" due to unknowns not accounted for by mathematicians or systems analysts. The limitations inherent in the methods of obtaining visual detection estimates are outlined. To begin with, the use of laboratory data to predict, with a mathematical model, visual performance in the operational situation presents a problem of "translation" to different conditions. This generally requires the use of "field factors" which perform a quantitative adjustment by applying a subjectively assessed "correction factor." The need for field factors is considered generally to detract from the precision and validity of the results.

There are other difficulties in acquiring data through the use of flight tests. Some of these have to do with the cost per data point and associated experimental constraints, such as sample size, lack of repeatable conditions, and unmanageable experimental design, despite the apparent validity of a real-life search task.

Data collected in operational settings, however, tend to be inaccurate due to limited available recording equipment and the difficulty of establishing objective conditions, or "air truth." This type of data is, nonetheless, real and no correction factors are necessary.

Simulation methods, though versatile and controllable, face the difficulty of having to determine the required level of fidelity for valid results. Erickson (76) points out the basic trade-off, that along the spectrum of data collection methods, control over the variables increases as the psychophysical experiment is approached, but applicability to the real world decreases.

General Research and Development. Despite these difficulties in obtaining data, modeling lies at the core of an understanding of the visual detection process. If all the significant parameters are properly formulated, accurate predictions of detection performance should be possible. Moreover, the existence of a useful model helps in structuring meaningful and key research questions, and thus contributes to the selection of efficient and economic research.

Design Questions. The primary utility of model outputs lies in the area of system design requirements and considerations. The application of such outputs as range and probability of detection to weapon system specification and collision avoidance procedures is of prime interest. The decision as to whether existing procedures are adequate or whether additional technology may be required to aid the searching observer may be based on the predicted probabilities of detection (with sufficient time to respond) generated by the model.

Background and Major Modeling Trends

The Detection Lobe. The foundations for modeling the visual search process were first set down by Koopman (129) while working for the U.S. Navy on the air-to-sea search problem during World War II. He used existing data on detection thresholds and single glimpse probabilities to derive a "detection lobe" equation relating threshold contrast as a function of target size and angle off-axis, or retinal position. The concept of a visual detection lobe was borrowed from radar terminology and theory, and has dominated most modeling formulations to date. The lobe refers to a three-dimensional pear-shaped volume which extends outward along the line of sight and depicts the relationship of threshold detection range to angle off the foveal axis for a given target contrast. This lobe can be observed pictorially in Figure 39. This lobe can also be expressed as a "threshold curve" as in Figure 40, taken from Short (195), in which the off-axis angle at which detection may occur is dependent upon the ratio of threshold target diameter to actual target diameter, i.e., α_l/α_t. If this ratio, referred to as the liminality ratio, is greater than 1, the target will not be detected. Lower ratios will permit targets to fall within the lobe area and hence be considered detectable. Moreover, the effect of various levels of contrast on lobe shape is clearly shown in Figure 41 from Heap (107).

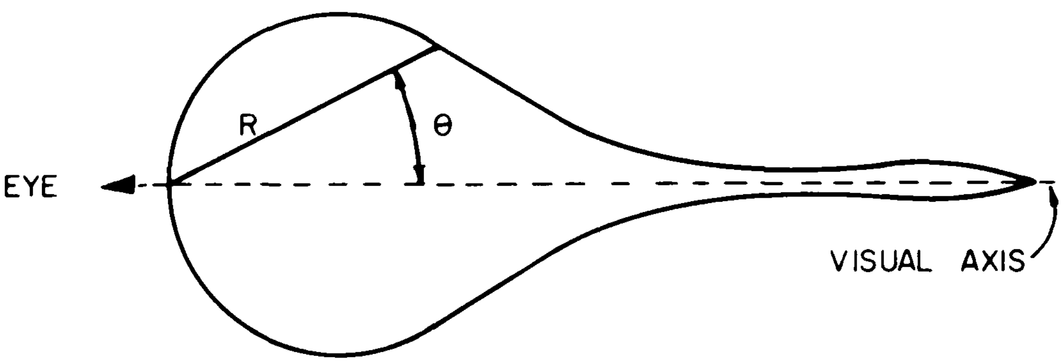

Figure 39. Cross-section of detection lobe where R is the range-to-lobe boundary and θ is the angle off visual axis.

An estimate of a single glimpse probability of detection, P_{sg}, can be made by considering the projected cross-sectional area of the lobe with the search field at a given range. A target that falls within this angle is given a P_{sg} equal to the lobe size divided by the total search field area.

Lamar's lobe equations are formulated as follows:

$$C_t = 1.55 + 15.2/\alpha^2 \quad , (\theta < 0.8 \text{ deg}) \tag{4}$$

and

$$C_t = 1.75\,\theta^{1/2} + 19\theta/\alpha^2, (\theta > 0.8 \text{ deg}) \tag{5}$$

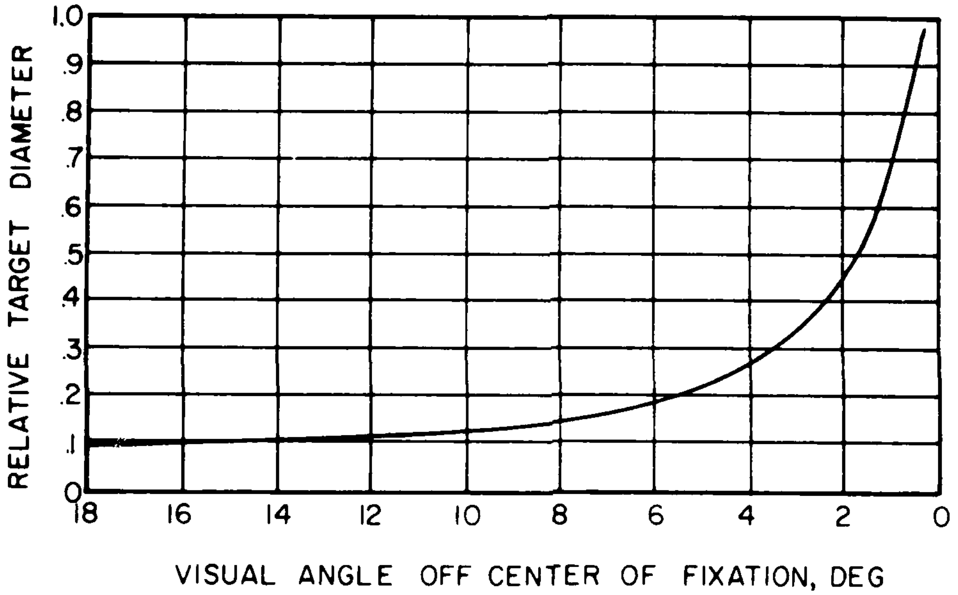

Figure 40. Threshold "detection lobe" curve (195, p. 18).

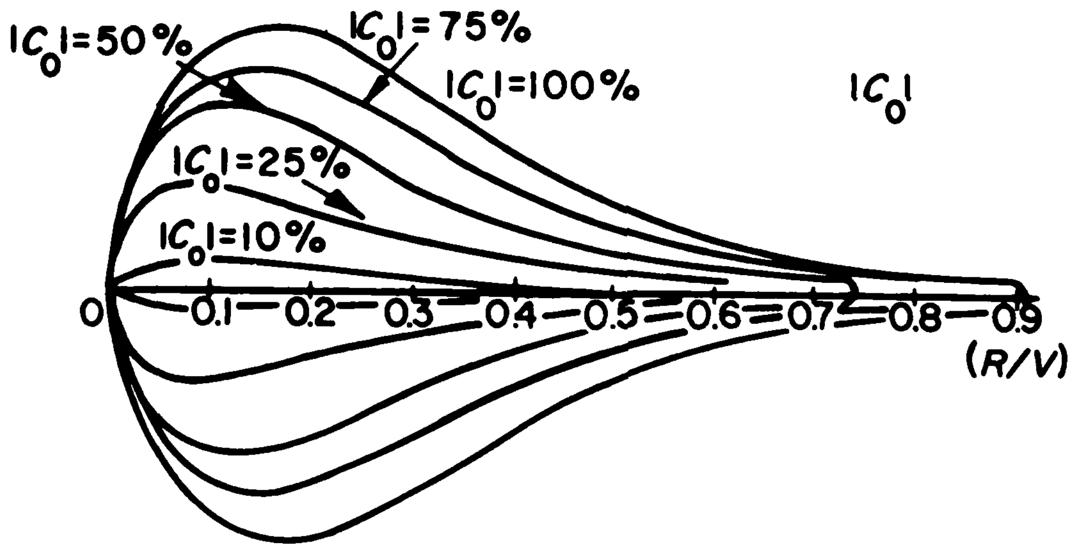

Figure 41. Sample visual detection lobe, object contrast effects (107, p. 170).

where r is angular subtense of target (min), [illegible] is angle off axis (deg), and C_t is percent contrast at threshold.

Koopman made the assumption that the glimpses of the searcher are independent of one another, or random. Although this assumption seems to be legitimate for the air-to-sea context, it may not apply equally well in other search situations. This question will be considered further in the context of the model applications to types of search fields.

Other approaches. Rather than taking the psychophysical threshold data as given and working from there, some theorists prefer to approach the modeling problem by describing the physiological processes that go into making a threshold response. Neural theories of visual detection are contrasted by Blackwell (27) with physical quantum theories as models of the entire visual system concerned with the transformation of the stimulus to sensory events and related decision processes without specifying the exact neural site and activity. The quantum theories consider the precise neural receptors (cones) involved in the detection event.

The decision-making model of Tanner and Swets (204) follows the basic framework of signal detection theory and is rejected by Blackwell because of contradictions that arise when the range of stimulus magnitudes is extended. Moreover, the mechanism relating stimulus to response is considered to be both random and deterministic by Kincaid (123), who thus rejects the notion of a fixed threshold.

Among the various theories of detection probabilities are those that consider the search process to be best described by a "random walk" Markov chain model (Cowan, 53; Kirkpatrick, 124), in which correct and incorrect acquisitions are considered as absorbing states which determine cumulative probabilities. This distribution, though similar in shape, is not the exponential distribution generally employed when glimpses are considered random. Kirkpatrick (124) claimed to show a close agreement between predictions and observations with this model that assumes that parameters do not vary with time. However, Enoch (68) demonstrated that parameters such as direction of fixation and interfixation distance changed when degradation is introduced, and thus concluded that it is unlikely that a random walk model is appropriate.

Air-to-ground models. A considerable amount of work has been conducted in an effort to model the air-to-ground acquisition task. Due to the complex nature of the background and the need to discriminate specific targets in military applications, the models must include additional background parameters and must also be concerned with recognition as well as detection. However, the basic approach used to describe the acquisition process can be applied to the air-to-air case by appropriate modifications or deletions of portions of the models.

The vast literature on air-to-ground target acquisition was reviewed in a report by Greening (90), who chose six principal models for detailed evaluation along a common set of criteria. Among those models included for comparison were two Air Force models (DETECT I, II, and MARSAM II), a Navy model (VISTRAC) described by Bradford (39), as well as models developed by the Autonetics Group of Rockwell International, the General Research Corporation, and the Stanford Research Institute. A number of other models were reviewed in the Greening (90) report for their pertinent ideas. Many of the same sources were reviewed for their relevance to the present investigation of air-to-air search.

Six measures were used by Greening as a basis for comparions. These are:

1. Incorporation of significant quantities,
2. Nature of the output,
3. Sensitivity to significant variables,
4. Range of applicability,
5. Evidence of validity, and
6. Electronic Data Processing (EDP) characteristics and requirements.

The "significant quantities" were broken down into subcategories which generally fall within those described in the section "Stimulus Characteristics." These are

1. Geometric characterisitics of observer/observed world situation,
2. Characteristics of the visual scene, and
3. Characteristics of the observer.

An outline of the geometric characteristics is presented in Table 3.

Several of the remaining measures of comparison were similarly outlined within a tabular context by Greening (90) and later enlarged upon to include British models (1974).

Sensitivity is depicted in Figures 42 through 45 for the most pertinent variables. Here, sensitivity refers to the relative variation in output as a function of different input parameters of the models. The input parameters considered most important were selected for the sensitivity study. These are search area, flight speed, target offset,

TABLE 3. GEOMETRIC CHARACTERISTICS (90, p. 91)

	MARSAM II	GRC/A	SRI	VISTRAC	DETECT II & III	AUTONETICS
1. Search area						
a. Shape	Circle on ground	Keystone-FOV of sensor	Keystone-±45° from beam of aircraft	Keystone-±4.25° to ±42.5° from flight axis	Circle on ground	Not specified
b. Maximum extent from observer	Terrain mask or meteorological range	Sensor FOV	Maximum target detection range	Terrain mask	Input	Maximum target detection range
c. Closest point to observer	Masked by aircraft	Sensor FOV	Input	Masked by aircraft	Input	Masked by aircraft
2. Flight Path						
a. Type	Straight & level	Not relevant	Straight & level segments	Straight & level	Straight & level (II) or orbit (III)	Straight & level
b. Target offset	Input	Not specified	Input	Input	Input	Input
c. Speed	Input	Not specified	Input	Input	Input	Input
d. Altitude above search area	Input	Input	Input	Input	Input	Input

target/background contrast, target size, and scene luminance.

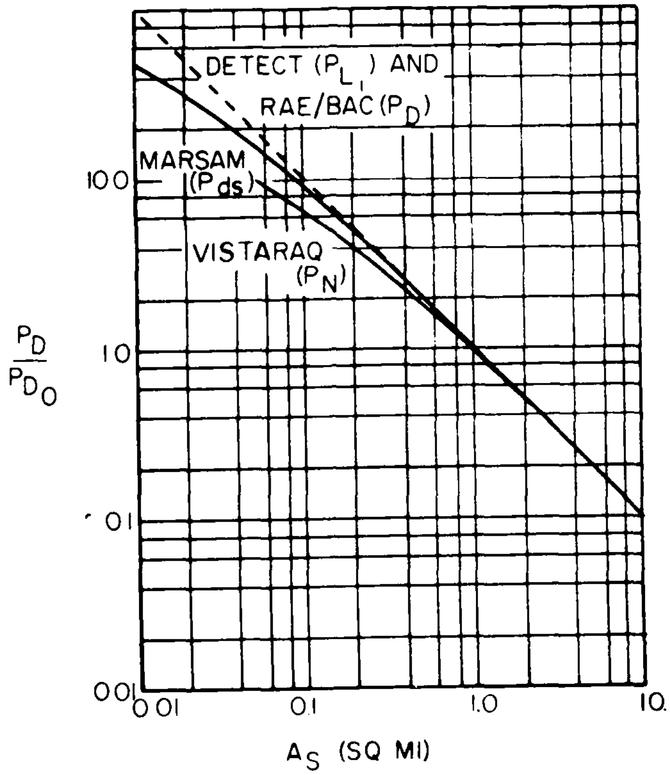

Figure 42. Effect of search area upon detection performance (normalized) (90, p. 73).

Some of the noteworthy limitations on range of applicability are that the models consider only static or quasi-static targets and level flight, and do not provide sufficiently for the effects of masking, clutter, and glare. Moreover, the models are limited to observers with "normal" vision and "standard" search techniques (random or systematic), with no provision for workload variations except in the case of VISTRAC.

Greening (90) found most of the models to share certain features such as (1) a strong emphasis on optical elements with a corresponding neglect of cognitive factors, (2) over-reliance on laboratory data, and (3) limited evidence of overall validation.

The evaluation against the selected criteria yielded other general findings:

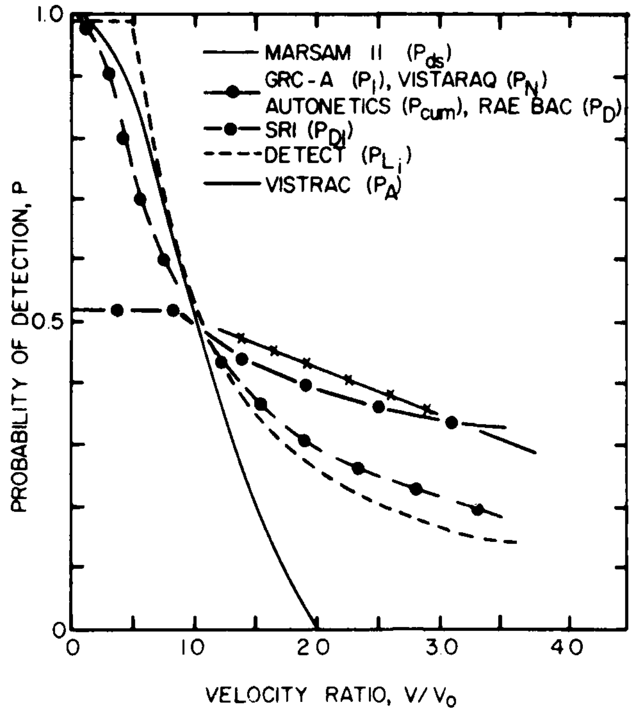

Figure 43. Effect of flight speed on probability of detection (90, p. 48).

1. Some significant variables have been omitted from all the models, such as observer characteristics;

2. Comparisons between outputs are difficult because of wide differences in form;

3. Sensitivities are different from model to model;

4. Applications are limited: level flight, stationary target, etc.;

5. Evidence of field validity is very difficult to obtain; and

6. EDP requirements are extremely variable.

In a subsequent report, Greening (91) took a closer look at the British modeling effort in target acquisition. Early mathematical formulations, provided by Heap of the Royal Air Force Establishment (RAE), generally followed the conceptions of Koopman and Lamar and concentrated on calculations of maximum sighting ranges (Heap, 107). Heap's "visual carpet" is presented in Figure 46. Much of the research work

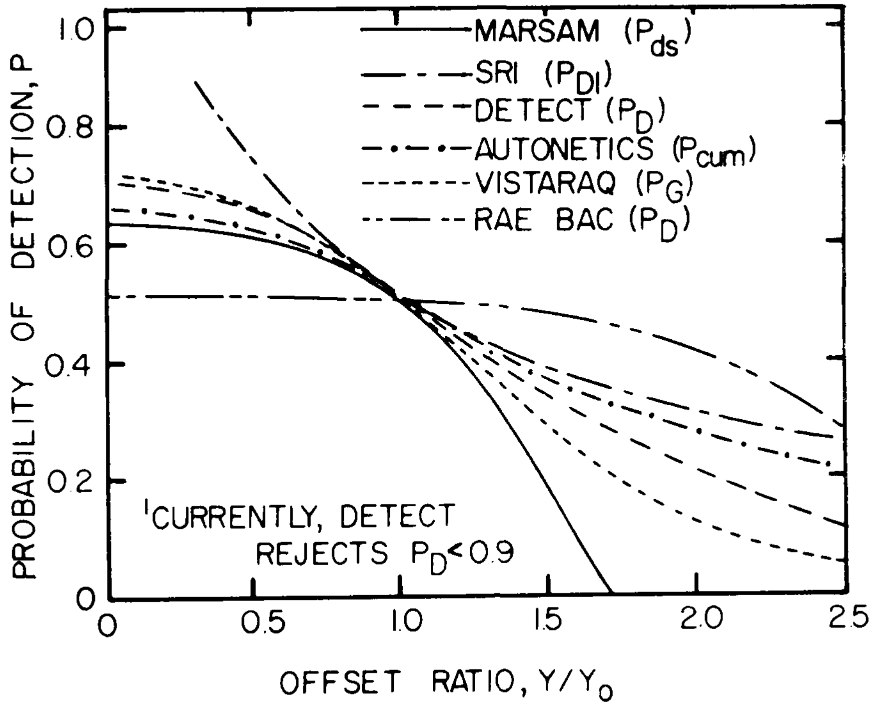

Figure 44. Effect of target offset on probability of detection (90, p. 46).

that grew out of this model framework was conducted by Davies who utilized the contrast threshold data of Blackwell for the fovea, and those of Taylor for the periphery. This RAE model is basically concerned with detection in the air-to-ground context. Although Davies (57) reports a good concordance of RAE theory with experimental results, he nevertheless found the visual lobe theory extremely optimistic for small targets. This effect can be clearly observed in Figure 47.

More recent work in England by Overington (175) of the British Aircraft Corporation has taken a unique turn by relatingsingle-glimpse probability to the stimulus value of the target which is considered to be a function of contrast, luminance, and the number of retinal receptors. Overington simply considers that the retinal image of a visual scene contains all the pertinent stimulus information in a retinal region of maximum illuminance gradient. This stimulus value can be averaged over approximately one receptor spacing.

The notion of contrast being specified by a luminance gradient has been considered by other researchers, as noted in Overington (175), who concluded that visibility thresholds are determined by contrast along a border rather than by some value averaged over the entire surface.

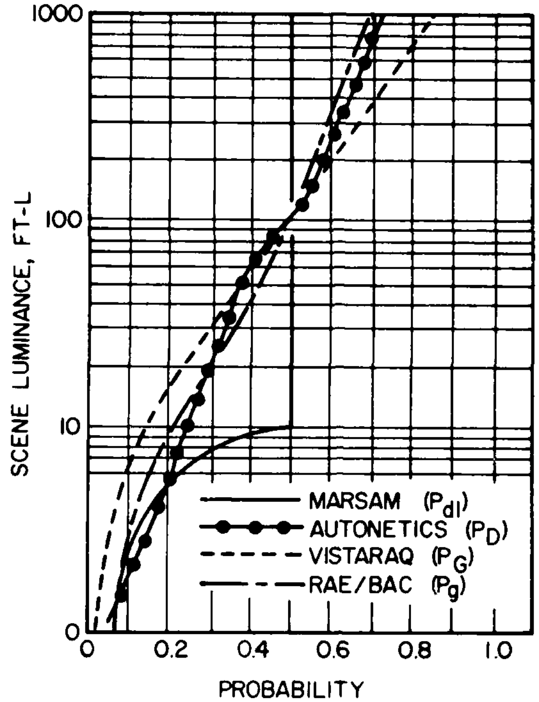

Figure 45. Effect of scene luminance on probability of detection (90, p. 50).

In the Overington (175) model, the expression for sensation produced in the observer by target contrast includes both a motivational term and a blur correction factor. These are unique features not found in the other models presented.

Another comprehensive acquisition model based on much of the previous British and American modeling notions was developed by Owen of the Defense Operations Analysis Establishment (DOAC) and is referred to as VISTARAQ. The VISTARAQ model includes some unique characteristics in its search submodel, such as alternative types of search area, with provisions for a "volume" search applicable to the air-to-air context. In addition, the detection submodel includes a glare correction factor which is not found in other models.

A series of tabulations is presented by Greening (91) to summarize the formulations of the parameters of these various models. A number of these are reproduced in Tables 4 through 15 to demonstrate the range of expressions and approaches used to describe the significant parameters of the air-to-ground models covered in this discussion, as well as their outputs and EDP requirements. They are also presented for their potential relevance to the air-to-air models

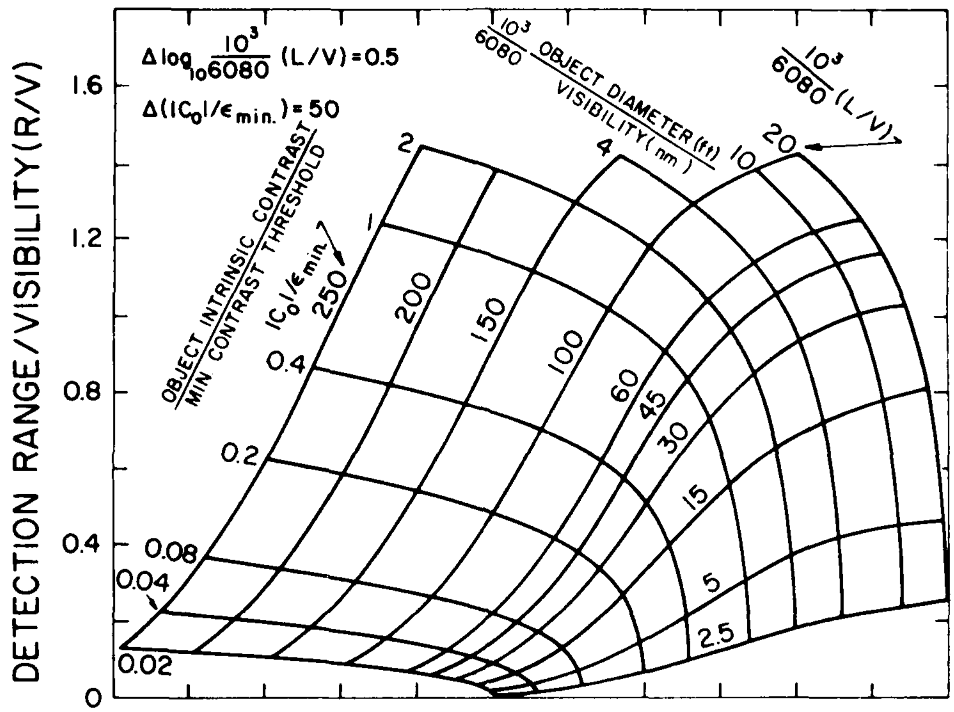

Figure 46. Visual carpet for b = 1.0, based on shape of Blackwell and McCready threshold curve for 1/3 s time (107).

which will be discussed below. Figures 48 and 49 give the threshold curves and single glimpse probability functions for the selected models.

Although several of the primary sources behind the models treated above were not available for review at this time, pertinent summary information was abstracted for the sake of completeness from subsequent articles by the same authors or from the comprehensive review reports provided by Greening (90, 91).

Specific Air-to-Air Modeling Attempts

Examples and directions. The relevance of the air-to-air acquisition problem to both military and civilian applications is demonstrated by an apparent increase in the number of published technical papers addressing the subject in recent years. The mathematical formulations basically follow the directions provided by previous search theory developed for air-to-ground models.

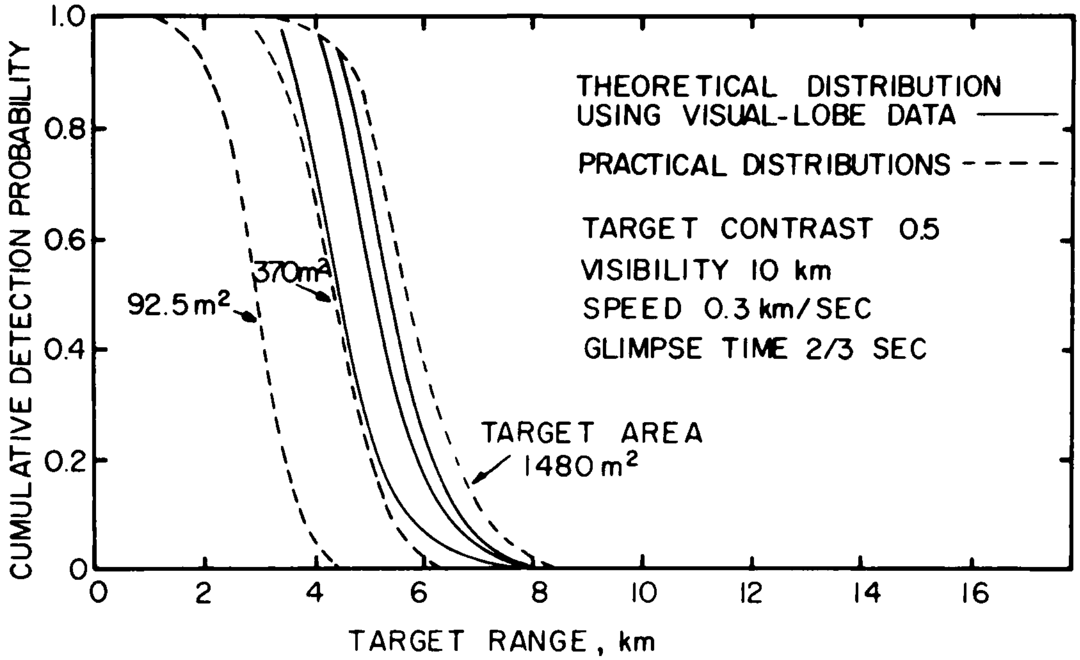

Figure 47. Theoretical effect of target size using visual lobe equation (57).

Although Erickson and Burge (76) offer caution concerning the hazards of extrapolation from data bases generated under different contexts, they nevertheless outline formulae derived from the pioneering research work discussed earlier. These formulae are useful for various calculations of interest. An expression for maximum range under no haze conditions ($C_o \approx C_r$) as well as a correction for the empty field are given:

$$R_m = 0.1655\sqrt{C_o - 1.565\ A} \quad \text{(no haze)} \tag{6}$$

where A is target area, while multiplying R_m by 1/2 will yield the empty field range.

Moreover, a hard-shell detection probability is derived for a single glimpse, g, given by

$$g = \theta^2/[(H + \theta)(\phi + \theta)] \tag{7}$$

where 2 H = azimuth angle of search field, 2 ϕ = elevation angle, and 2 θ = lobe angle width at target range. The search field is depicted geometrically in Figure 50. A table was also provided by Erickson and Burge which gives single glimpse detection probabilities, g_i, for variations in the above parameters (Table 16).

TABLE 4. SEARCH AREA FORMULATIONS IN EIGHT MODELS (91)

MARSAM II	Circle on ground	Terrain mask or meteorological range	Masked by aircraft structure (input)
GRC/A	Keystone - FOV of sensor	Top of sensor FOV	Bottom of sensor FOV
SRI	Keystone - ±45° from beam of aircraft	Maximum computed target detection range	Input
VISTRAC	Keystone - ±4.5° to ±42.5° from flight axis	Terrain mask	Masked by aircraft structure (input)
DETECT II & III	Circle on ground	Input	Input
AUTONETICS	Not specified	Maximum target detectable range	Masked by aircraft structure (input)
VISTARAQ	Stationary rectangle on ground, or advancing rectangle on ground	Input	Input
RAE/BAC	Stationary rectangle, may be vignetted by keystone	Top of "window" or input	Bottom of "window"

TABLE 5. FLIGHT PATH LIMITATIONS (91)

Model	Type	Target Offset	Speed	Altitude
MARSAM II	Straight and level	Input-fixed*	Input-fixed	Input-fixed
GRC/A	Not limited	Not specified	Not specified	Input
SRI	Straight and level segments	Input-limited (see "Search Area")	Input-fixed	Input-fixed
VISTRAC	Straight and level	Input-limited (see "Search Area")	Input-fixed	Input-fixed
DETECT II & III	Straight and level (II) or Orbit about target (III)	Input-fixed	Input-fixed	Input-fixed
AUTONETICS	Straight and level	Input-fixed	Input-fixed	Input-fixed
VISTARAQ	Not restricted	Input - variable	Input - variable	Input-variable
RAE/BAC	Straight and level	Input-fixed	Input-fixed	Input-fixed

* "Fixed" means single-valued for one encounter.

TABLE 6. REPRESENTATION OF TARGET APPARENT SIZE (91)

Model	Formulation
MARSAM II	$\beta = K\,\bar{D}_t/R_s$ where $\bar{D}_t = [h(\frac{w+1}{2})\cos \emptyset + wl \sin \emptyset]^{1/2}$
GRC/A	$\beta = KA_t^{1/2}$ where $A_t = \frac{\lvert\vec{S}_1 \cdot \vec{R}_s\rvert + \lvert\vec{S}_2 \cdot \vec{R}_x\rvert + \lvert\vec{S}_3 \cdot \vec{R}_s\rvert}{\lvert\vec{R}_s\rvert}$ ($\vec{S}_i$ is a vector representation of the area of the i^{th} side of the target)
SRI	$\beta = K\left[\frac{A_t}{2}\left(\frac{1}{R^2_{s\ min}} + \frac{1}{R^2_{s\ max}}\right)\right]^{1/2}$ (SRI model also permits division of target into sub-regions)
VISTRAC	$\beta = K\left[\frac{h \cos \emptyset (l \cos \psi + w \sin \psi) + lw \sin \emptyset}{\pi}\right]^{1/2}/R_s$
DETECT II & III	$\beta = KA_t^{1/2}$ (A_t is input directly)
AUTONETICS	$\beta + KA_t^{1/2}$ where $A_t = \frac{hw \cos \emptyset + lw \sin \emptyset}{R_s^2}$
VISTARAQ	$n = f(A_t)$ where n is number of visual receptors covered by image. $A_t = w \times h$
RAE/BAC	$\beta = \left(\frac{4A_t}{\pi}\right)^{1/2}$ where A_t is projected area of target

NOTE: In this table, β is a characteristic angular subtense of the target; A_t is projected area of target; h,w,l are height, width and length of target; R_s is slant range; Ø is lookdown angle; ψ is off-axis angle.

TABLE 7. REPRESENTATION OF APPARENT TARGET/BACKGROUND CONTRAST (91)

Model	Formulation	
MARSAM II	$C = \dfrac{\lvert B_t - B_b \rvert}{B_b}$	where B_t and B_b are obtained from inherent contrast and an atmosphere model
GRC/A	$C = \dfrac{\lvert B_t - B_b \rvert}{B_b}$	(GRC/A is an EO sensor model; hence, apparent contrast involves elements not appropriate to visual models)
SRI	$C_T = R_H/R_L$	where R_H, R_L are highlight and lowlight reflectance; C_{TA} (apparent "contrast") is derived from C_T and an atmospheric model.
VISTRAC	$C = \begin{cases} \dfrac{B_t - B_b}{B_t} & \text{for } B_t \geq B_b \\ \dfrac{B_t - B_b}{B_b} & \text{for } B_b > B_t \end{cases}$	where B_t and B_b are modified by an atmospheric model
DETECT II & III	C is derived from C_o, an input, and an atmospheric model	
AUTONETICS	C is derived from C_o, an input, and an atmospheric model	
VISTARAQ	$C = \dfrac{B_t - B_b}{B_b}$	derived from input quantities and an atmospheric model
RAE/BAC	$C = \dfrac{B_t - B_b}{B_b}$	derived from input quantities and an atmospheric model

NOTE: In this table, C is apparent target/background contrast; B_t, B_b are apparent target and background luminance.

TABLE 8. REPRESENTATION OF VISUAL MASKING (91)

MODEL	TYPE OF MASK: AIRFRAME	CLOUDS	VEGETATION	TERRAIN
MARSAM II	$\emptyset_{max}$, an input	Not represented	$P_{FLOS} = f\left(\frac{h_f}{W_f}, P_f, \emptyset\right)$	$P_{TLOS} = f(R,H)$, from lookup tables for varied terrains.
[illegible]RC/A	Not represented	Not represented	Not represented	Not represented
SRI	Assumed ±45° from the beam	Random draw for input likelihood of cloud cover	Random draw	Random draw
VISTRAC	$\emptyset_{max}$, an input	Not represented	Not represented	An input to determine R_{max}, otherwise not represented.
DETECT II & III	Not represented	Not represented	P_{FLOS}, from a sub-model	P_{TLOS}, an input
AUTONETICS	$\emptyset_{max}$, an input	Not represented	Not represented, except as R_{max}	Not represented, except as R_{max}
VISTARA 2	Not represented	Can use random draw	Can use Doran formula	Horizon computed; can use Doran formula.
RAE/BAC	Retangular window on flight axis; dimensions input.	Not represented	Not represented	Not represented

NOTE: In this table, $\emptyset$ is lookdown angle; h_f, W_f are height and width of foliage elements; P_{TLOS}, P_{FLOS} are probability of LOS due to terrain, foliage; R is slant range; H is altitude of observance, P_f is total fraction of area covered by foliage.

TABLE 9. REPRESENTATION OF SCENE CLUTTER (90)

MODEL	CLUTTER REPRESENTATION
MARSAM II	$P_{d3} = \frac{1}{\left(1 + \frac{M}{29\, t_g^{.93}}\right)^{1.29}}$ $M = \bar{M} A_g$ t_g is glimpse time; $\bar{M}$, an input, is average number of "confusion objects" per unit area; A_g is glimpse area.
GRC/A	$P_3 = \frac{1}{\left(1 + \frac{M}{29\, T^{.93}}\right)^{1.29}}$ M is number of objects in sensor field of view, an input; T is sensor frame time.
SRI	Clutter not explicitly modeled. But probabilities of misrecognition and other clutter-related quantities are estimated from the detailed scenarios by trained judges.
VISTRAC	Clutter not explicitly modeled. There may be clutter elements in one or more of the field-evaluated constants.
DETECT II & III	Clutter not modeled.
AUTONETICS	Clutter not modeled explicitly. Can be reflected in value of P_L, an input.

TABLE 10. OBSERVER THRESHOLD FOVEAL PERFORMANCE REPRESENTATION (91)

Model	Formulation
MARSAM II	$\log C_T = \frac{1.033}{\log \beta + .142} + .072\ (\log \pi B_b)^2 - .425(\log B_b) - 1.492$ (This form is for low light levels. Above $\pi B_b = 10$, last 3 terms are replaced by a constant of -1.845)
GRC/A	$\log C_T = \frac{1.033}{\log \beta + .142} - 1.845$ (Model limited to $B_b \geq$ 10 ft L)
SRI	β vs C_T a lookup table based on NDRC monographs
VISTRAC	$C_T = 1.57 + \frac{14.86}{\beta^2}$ (VISTRAC is limited to daylight)
DETECT II & III	$C_T = 1.55 + \frac{15.2}{\beta^2}$ (DETECT is limited to daylight)
AUTONETICS	$(C - C_T)^{1/2} = \frac{2}{\beta\left([1 + (\log B_b + 3)^2]^{1/2} - .8\right)}$ (Autonetics model assumes C_T is fixed - usually .02)
VISTARAQ	$\left[\log \frac{B}{B_o} \cdot \log \frac{C}{C_o} \cdot \log \frac{n}{n_o}\right]$ = constant, except for a correction for $\beta < 5$ min. (B_o, C_o, n_o are "minimum effective" values)
RAE/BAC	β, C_T and B_b from tabulated data based on Blackwell and Taylor.

NOTE: In this table, β is characteristic target subtense; C_T is contrast threshold; B_b is background luminance; n is number of visual receptors involved.

TABLE 11. OBSERVER THRESHOLD PERFORMANCE: OFF-AXIS (91)

Model	Formulation
MARSAM II	Off-axis performance shows up in definition of effective single-glimpse area, $\bar{A}_{eg}$. $\bar{A}_{eg}$ = 5° is usual value. Assumes performance constant out to 5°.
GRC/A	$C_{T_{OFF}} = C_T \left[1 + \frac{.803(\Theta-.54)}{\beta^4} \right]$ (NOTE: GRC/A has no luminance term - limited to $\geq$10 ft L)
SRI	Not represented.
VISTRAC	$C_{T_{OFF}} = 1.75\ \Theta^{\frac{1}{2}} + \frac{18.75\Theta}{\beta^2}$ for $\Theta \geq 0.8°$ (NOTE: VISTRAC has no luminance term - limited to daylight.)
DETECT II & III	$C_{T_{OFF}} = 1.75\ \Theta + \frac{19\ \Theta}{\beta^2}$ for $\Theta \geq 0.8°$ (NOTE: DETECT has no luminance term - limited to daylight.)
AUTONETICS	Not represented.
VISTARAQ	$n = f(A_t, P_\Theta)$ where $P_\Theta = 293 + \frac{.81}{(\Theta + .014)^2}$ (P_Θ is receptor density: $\frac{\text{cones}}{\text{steradian}} \times 10^{-4}$)
RAE/BAC	$C_{T_{OFF}}$ from tables based on Taylor's off-axis data.

NOTE: In this table, β is a characteristic target angular subtense (min); Θ is angle off visual axis (deg); $C_{T_{OFF}}$ is off-axis contrast threshold.

TABLE 12. DISTRIBUTION OF SEARCH EFFORT (91)

MODEL	SEARCH FORMULATION
MARSAM II	Expected search performance based on non-overlapping glimpses over effective search area: $A_{S_{eff}} = P_t P_{LOS} (A_S - \Sigma n_i A_i)$ where P_t is "likeliness" factor; P_{LOS} is line of sight probability; Σn_i is area occupied by targets.
GRC/A	Expected search performance based on random glimpses over sensor field of view.
SRI	Expected search performance proportional to $T^{\frac{1}{2}}$ up to T = 5 sec; no effect of more glimpses beyond 5 sec.
VISTRAC	Expected search performance systematic; line of sight moves in circular arcs at fixed depression angle.
DETECT II & III	Search area covered with minimal (i.e., non-overlapping) glimpses.
AUTONETICS	Expected search performance a part of P_L, an input. No explicit assumptions on distribution of search effort.
VISTARAQ	Expected search performance based on random glimpses over field of view.
RAE/BAC	Expected search performance based on random glimpses over field of view.

NOTE: In this table, T is search time available; A_s is search area; P_L is likelihood of looking at the target.

TABLE 13. DETECTION PERFORMANCE REPRESENTATION (91)

MODEL	FORMULATION
MARSAM II	$P_{dl}^* = 0.5 \pm 0.5 \left[1 - \exp\left[-K(CR-1)^2\right]\right]^{1/2}$ for $CR \geq 0.5$; $P_{dl}^* = 0$ otherwise. (P_{dl}^* is detectability; detection depends also on search and line of sight.)
GRC/A	$P_D = 0.5 \pm 0.5 \left[1 - \exp\left[-K(CR-1)^2\right]\right]^{1/2}$ for $CR \geq 0.5$; $P_D = 0$ otherwise.
SRI	$P_{DI} = 1 - \exp\left[-K(S_A T_E D_A)\right]$ where P_{DI} is probability of detection and/or recognition; S_A, T_E, D_A are terms related to target size, search time, and target contrast, respectively.
VISTRAC	$P_A = 1 - \exp\left[-K(CR-b)^m \; dt\right]$ where P_A is probability of acquisition, including recognition; b and m are constants.
DETECT II & III	$P_F = 0.5 \pm 0.5 \left[1 - \exp[K(CR-1)^2]\right]^{1/2}$ for $CR \geq 1.5$; $P_F = 0$ otherwise. P_F is probability of detection if viewed foveally.
AUTONETICS	$P_D = \exp\left[-\left(\frac{2\alpha^2}{\beta^2(C-C_T)}\right)^M\right]$ $M = 1$ for $\alpha^2/(C-C_T) > 2/\beta^2$ $M = 2$ otherwise.
VISTARAQ	$P_D = 0.5 + \frac{1}{\sqrt{2\pi}} \int e^{-z^2/2} dz$ where $z = \frac{(\log B/B_o \, . \, \log C/C_o \, . \, \log n/n_o) - K_T}{\sigma_{Bcn}}$
RAE/BAC	$P_{Dns} = \frac{1}{\sqrt{2\pi}} \int e^{-x^2/2} dx$ where $x = \frac{\log CR}{\sigma \log CR}$ and $P_{DS} = a'/A'$ where a', A' are effective visual lobe area and effective search area.

NOTE: In this table, P_D is detection probability; $CR = C/CT$; C is apparent contrast; C_T is threshold contrast; β is target subtense; α is resolution capability of eye at $C = 1$; B is scene luminance; n is number of receptors in image area.

TABLE 14. FORM OF MODEL OUTPUT (91)

MODEL	DETECTION	RECOGNITION/IDENTIFICATION	OTHER
MARSAM II	Number - P_D, averaged over three assumed conditions.	Number - P_R, averaged over three assumed conditions.	
GRC/A	Number - P_1, for the assumed frame time of the sensor.	Number - P_2, for the assumed frame time of the sensor.	
SRI	Number - P_D for this target encounter.	Numbers - P_R & P_I for this target encounter.	Probability of misrecognition, misidentification, etc.
VISTRAC	Curve - P_{Acum}, a curve showing cumulative probability of "acquisition" between integration limits.		Will compute and plot a "rate of acquisition" versus range.
DETECT II & III	Curve - P_{Dcum} as function of range. Curve - P_{Dcum} as function of time in orbit.		
AUTONETICS	Curve - P_{Dcum} as function of range.	Curve - P_{Rcum} as function of range.	
VISTARAQ	P_D and P_{Dcum} as a function of time and/or glimpses.	P_R and P_{Rcum} as a function of time and/or glimpses.	$P_{Acquisition}$
RAE/BAC	P_D (no search) at each range. P_g (search) at each glimpse. $P_{D\ (cum)}$ as function of range.		

TABLE 15. ELECTRONIC DATA PROCESSING REQUIREMENTS (90)

MODEL	COMPUTER SYSTEM	MEMORY SIZE	LANGUAGE	NO. OF EXECUTABLE SOURCE STATEMENTS	INPUT/ OUTPUT	PERIPHERAL DEVICES	EXECUTION TIME
"MARSAM II" HONEYWELL	IBM 7094	32K words	Fortran IV	3800	Card reader/ printer	2 magnetic tapes	$\simeq$5 sec.
WPAFB	CDC 6600	22K words	Fortran IV	3500	Card reader/ printer	Random access disk	$\simeq$0.5 sec.
GRC, MODEL A "NITEFLY"	CDC 3600	21K words	Fortran 63	1000	Card reader/ printer	None	$\simeq$5 sec.
SRI "SCREEN/AIR"	CDC 6400	65K words	CDC Fortran IV extended	7500	Card reader/ printer	Random access disk	
"VISTRAC"	CDC 6600	16.5K words (24K with plotting)	CDC Fortran IV extended	950	Card reader/ printer	None	6-10 sec.
DETECT MODELS: SAGF-WTFØ2 &-Ø6	Tymeshare	3K words	Fortran IV	115	Teletype	None	$\simeq$0.1 sec.
"DETECT II & III"	CDC 6400/ 6600	3K words	Fortran IV	120; 110	Card reader/ printer	None	$\simeq$0.1 sec.
AUTONETICS "VISUAL DETECTION MODEL"	IBM 370/ 165	57K bytes (84K with plotting)	Fortran IV	650	Card reader/ printer	Optional plotter	$\simeq$0.2 sec.

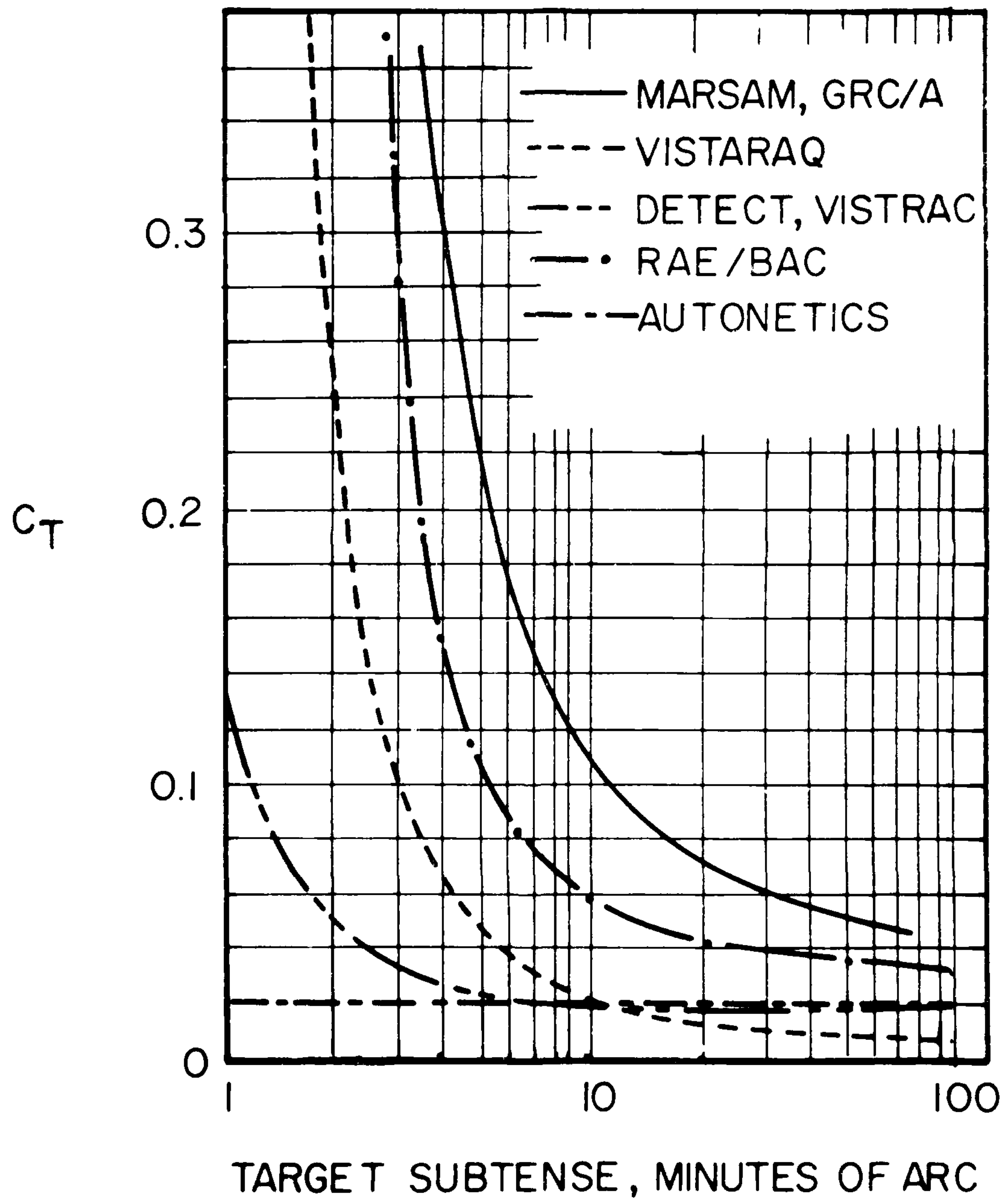

Figure 48. Threshold contrast as a function of target subtense (90, p. 47).

The cumulative probability at range n is then given by:

$$P_n = 1 - \exp[1/\Delta R \int_{R}^{Rn} \ln (a - g_i)dR] \qquad (8)$$

under the assumption that each glimpse is independent. The value of R refers to the change in range equivalent to the distance traveled between glimpses. This function is presented graphically in Figure 51 using the data of Table 16 for a 55 ft sq target with 30% contrast.

The range interval, ΔR, can be obtained by multiplying the relative closing velocity of the aircrafts by the time required for each glimpse. Now, a glimpse may be defined in this context as a cluster of successive eye fixations in a given small area. Although Erickson and Burge report that a glimpse time value of 1.65 s is generally agreed upon, they fail to list the sources and thus this designated value may best be considered as an assumption subject to further verification.

Indeed, the duration of each fixation has been determined on the average to be 0.28 sec by Ford et al. (79), who also report that the remaining 15% of the time the eyes are involved in movement, or saccades. They go on to conclude that the angle of travel during each saccade most often takes on a constant value of approximately 8.5 deg. This is called the azimuthal scan angle in the search context. Since the field of view used experimentally by Ford et al. (79) was rather small (30 deg), Short (195) conjectures that this scan angle will vary proportionately with the size of the search field but will remain constant for a given field. Although Short (195) agrees that a glimpse time is typically composed of 6 to 8 fixations which yields a corresponding range of approximately 1.5 to 2.0 seconds for one glimpse, he postulates that an alerted pilot or observer will tend to spend more time inspecting each area. Thus, glimpse time is clearly dependent on both the situation and the observer's scan patterns which may be subject to change through training or practice.

More recently, Gutmann et al. (96) have found that single fixations are much longer (e.g., > 600 ms) for dynamic search tasks than for static search tasks. Thus, generalization from the dynamic air-to-ground search model to the perceptually static air-to-air situation may be unsupportable.

The function depicted in Figure 51, which was derived from the formulations of Koopman (129), was also presented by Short (195) in his treatment of mid-air collision situations. Moreover, for the case of the unalerted pilot, Short (195) suggests that an overall search cycle exists which should include the time spent in navigation, t,

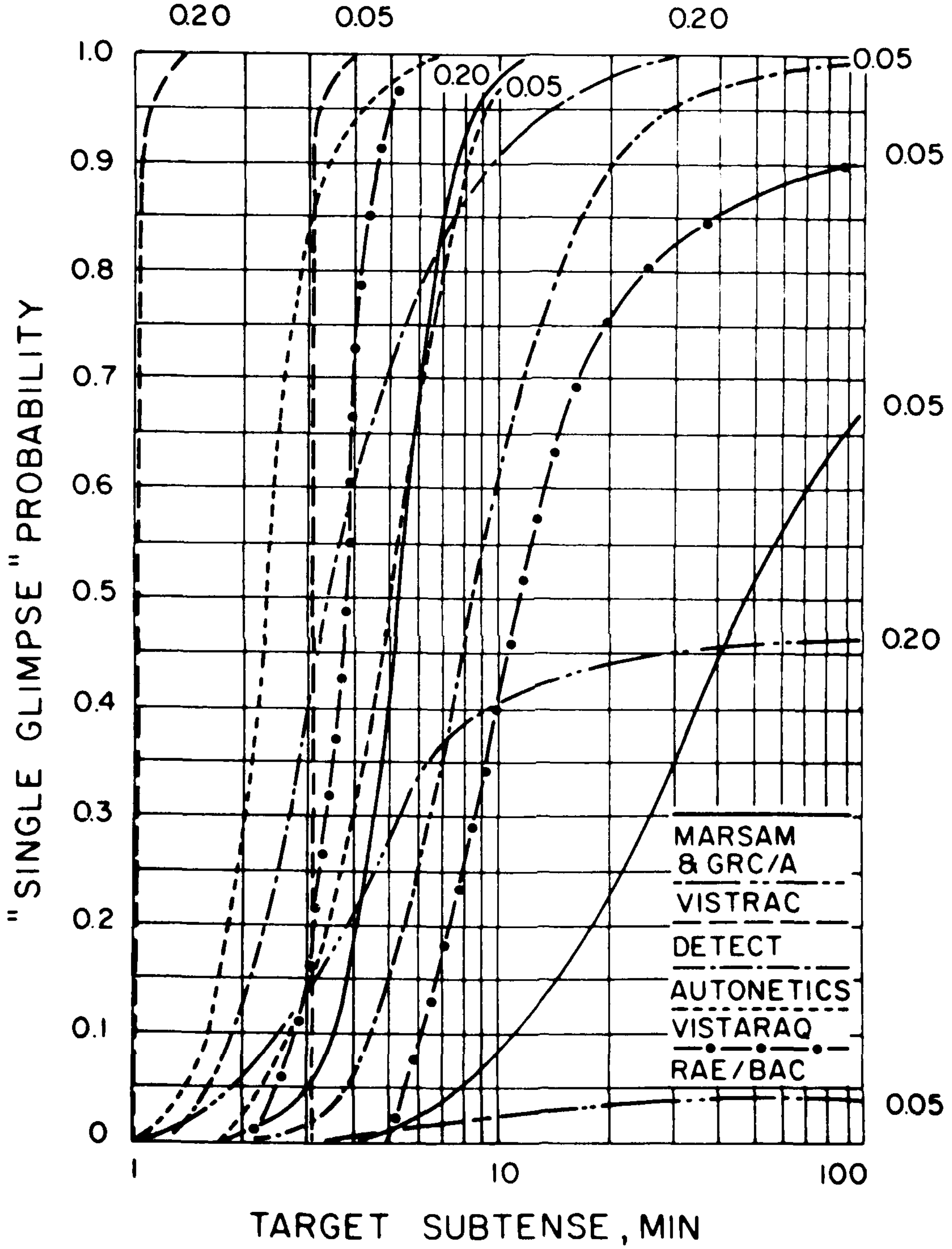

Figure 49. "Single glimpse" probability of detection as function of target subtense and contrast (90).

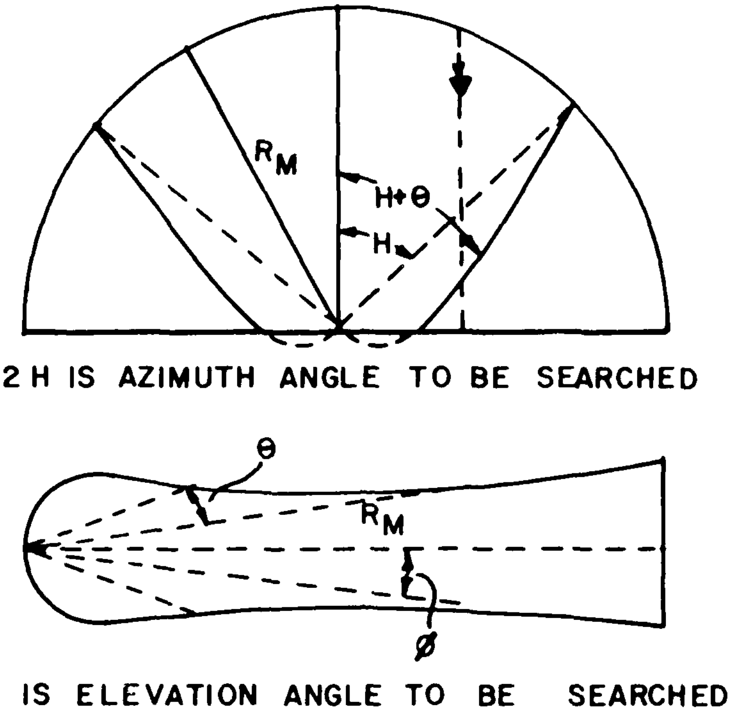

Figure 50. Azimuth and elevation search geometry (76).

between periodic searches, as well as a provision for dividing the total field to be searched into subsectors. Thus, search cycle time is given by:

$$\tau = 2\,m\,k\,T + t \qquad (9)$$

where T is the time for one glimpse, m is the number of glimpse sequences during one subsector, in which two glimpses are assumed per sequence, and k is the number of subsectors in the total field. The number of subsectors, k, is determined by dividing the total search field by the azimuthal scan angle for that field. This formulation leads to a slight modification in the range increment factor applied to the probability integral above, in which $1/\Delta R$ becomes $2m/V\tau$.

Short (195) goes on to conclude that although the area to be searched can be reduced by electronic aids, the target velocity, V, is clearly uncontrollable, while glimpse times, T, may nevertheless vary with training and context. Although Short's conception of search cycle has a logical and numerical appeal as a model parameter, the idea of two glimpses occurring per subsector has not been adequately demonstrated, and may be offensive to some visual scientists.

TABLE 16. DETECTION LOBE AND GLIMPSE PROBABILITIES (76)

R, nm	Θ, deg	g for $H = \pm 90°$ $\phi = \pm 30°$	g for $H = \pm 90°$ $\phi = \pm 15°$
0.6	50	0.2218	0.2733
1.3	16	0.0533	0.0789
2.0	8	0.0166	0.0275
2.6	5	0.0065	0.0115
3.3	3	0.0030	0.0055
3.9	2	0.0016	0.0029
4.6	2	0.0009	0.0017
5.2	1	0.0005	0.0010
5.9	1	0.0003	0.0007
6.5	1	0.0002	0.0005

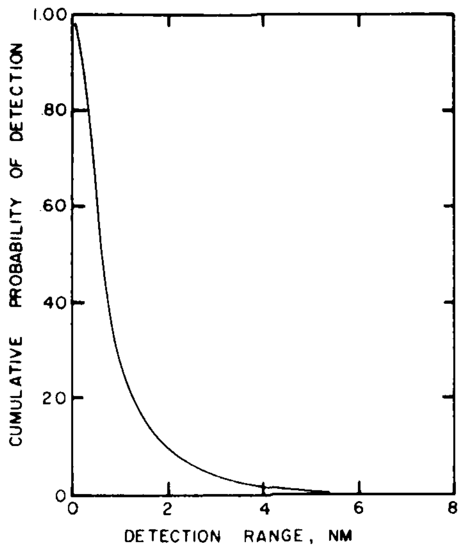

Figure 51. Cumulative probability of detection for target moving on radial path to or from an observer (76).

A recent review of the modeling of air-to-air target detection has been compiled by Akerman and Kinzly (3), in which five models are compared against controlled search experiments, and a visual search model called VIDEM is presented which is applicable to search in an unstructured visual field. The model includes four components which generally resemble those employed by Erickson and Burge (76): a limited contrast threshold, a frequency-of-seeing curve, a soft-shell search representation, and discrete cumulation of single glimpse probabilities (random glimpses).

The liminal contrast threshold, C_t, is for the case of 50% single glimpse detection probability, while remaining a function of target size, α, and retinal position, θ. The frequency-of-seeing curve is used as the mechanism for computing the single glimpse probabilities for contrasts other than at liminal threshold. This curve is represented as the normal ogive:

$$g(\alpha,\theta) = \Phi[(C/C_t - \mu)/\sigma] \tag{10}$$

in which the mean (μ) must equal unity for 50% detection probability, and σ varies with conditions. The commonly used frequency-of-seeing curve of Koopman (129) is similar in shape (Figure 52), but sets the probability of detection equal to zero for $C/C_t < 0.04$, while setting $P = 0.57$ for a liminal contrast ratio $C/C_t = 1.0$. This is the result of the definition used by Lamar for an eight-position forced-choice experiment.

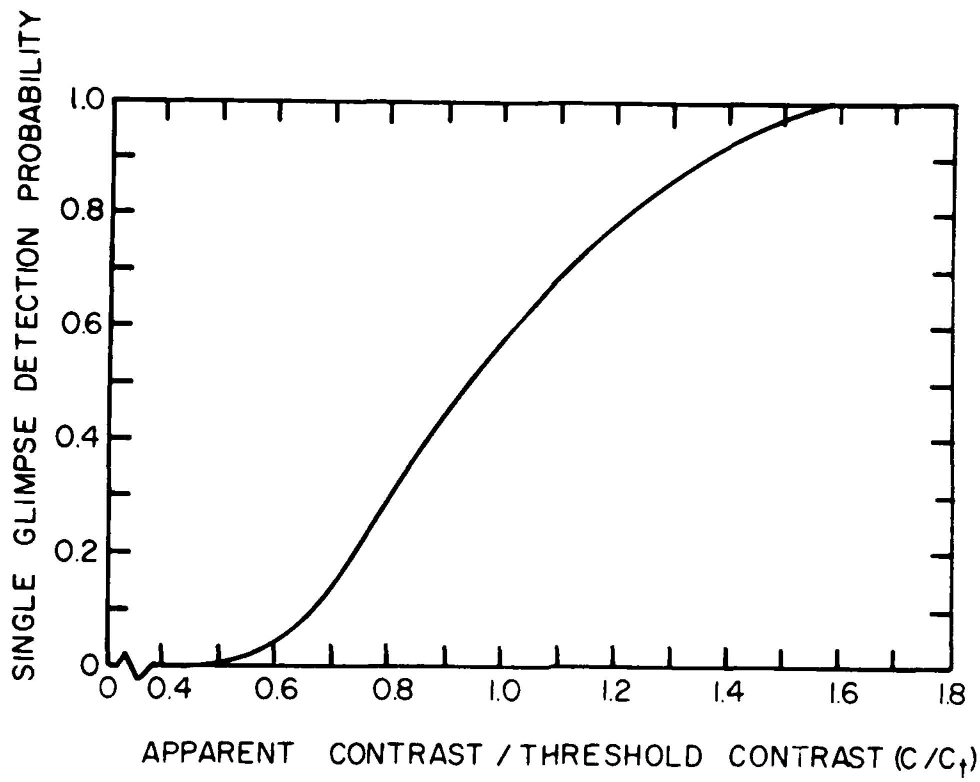

Figure 52. Koopman's empirical frequency-of-seeing curve (3).

The search representation in the VIDEM model does not use the visual lobe but employs the soft-shell model of Deutschman, Hammill, and Sugarman (59). This model establishes a probability density function $p(\theta')$ which considers all angles between the foveal axis and the target position in the search field. The angle θ' is thus the peripheral angle, or angle off-axis.

Single glimpse probabilities are computed from the above frequency-of-seeing function, $g(\alpha,\theta)$, through the following integral:

$$g = \int p(\theta')\ g(M\theta')\ d\theta' , \tag{11}$$

where M is magnification (M = 1 for unaided search). In practice, the integration interval is subdivided into 18 increments of 5 deg outward from the fovea. The single glimpse probability, $g(\theta')$, is computed at each θ' position and weighted by the probability, $p(\theta')$, of that angle falling within the search field. The $g(\theta')$ values are averaged to yield a probability for a single glimpse, g.

The VIDEM model can be used for other search distributions besides the uniformly distributed random process postulated for the empty field. The numerical values for the $p(\Theta')$ distribution would be all that would differ.

The cumulation method used in VIDEM assumes a conservation of probability in which glimpse probabilities are independent and is formulated as,

$$P_{cum(n)} = 1 - \exp\left[\sum_{i=1}^{r} \ln(1 - g_i)\right] , \tag{12}$$

which is the familiar exponential distribution. This equation is considered representative of both random and systematic search.

The five models chosen by Akerman and Kinzly for comparison are listed in Table 17, showing alternate representations of threshold contrast and associated parameters. The five models considered are: K/L (Koopman/Lamar); H/S (Hammill/Sloan); RAND (Corporation); GRC (General Research Corporation); and POE (developed by A. C. Poe, III for the U.S. Army Missile Research and Development Command). The different formulations result in different foveal threshold curves which are plotted together in Figure 53. The peripheral threshold curves are similarly plotted in Figure 54.

An initial screening of the five model candidates was conducted by comparing the models with two laboratory search experiments. The results are reported in Table 18, in which experimental mean detection times (τ) for a stationary target under various search parameters are compared with model predictions. The performance measures given in Table 18 indicate whether predictions are either fast (+) or slow (-) compared to the actual event cumulatives. The numeral values are Kolmogorov-Smirnov statistics. The sign ratings are useful for further field factoring of the models.

The K/L and Poe models both predicted early detection, whereas the GRC model often failed to provide any cumulation in detectability. The RAND model showed a mixed performance with no consistent trend. The best predictions were yielded by the Hammill/Sloan model for both large and small targets; yet intermediate size targets were not well predicted.

Two models were chosen for further evaluation against field test data. These were:

1. Hammill/Sloan -- with a frequency-of-seeing (f-of-s) curve of the form $N(\mu, \sigma)$ to be N(1.0, 0.25); and

2. A Composite Model -- H/S model for small targets and GRC for large targets with f-of-s curve of the form N(1.0, 0.3).

TABLE 17. SUMMARY OF CANDIDATE DETECTION MODELS (3)

MODEL	LIMINAL BRIGHTNESS CONTRAST THRESHOLD	FREQUENCY-OF-SEEING CURVE $\underline{M}$	FREQUENCY-OF-SEEING CURVE $\underline{\sigma}$
K-L	$\frac{0.0175\sqrt{\theta}}{f_1(B)} + \frac{0.198}{f_2(B)\,\alpha^2}$	0.97	0.27
H-S	$0.265\theta^{0.24} + 0.44\theta^{1.6}/\alpha^2$	0.97	0.27
RAND	$\left[1.0 + \frac{0.103(\theta-0.54)}{\alpha^{0.4}}\right] \cdot 10^{\frac{1.0}{\log_{10}\alpha + 0.5} - 2.0}$	1.00	0.39
GRC	$\left[\frac{1.0 + 0.303(\theta-0.54)}{\alpha^{0.4}}\right] \cdot 10^{\frac{1.033}{\log_{10}\alpha + 0.142} - 1.845}$	1.00	0.39
FCE	$a_o/\alpha^{b_o} + (\theta-0.6)\, a_1/\alpha^{b_1}$, $\theta \le 15$ $a_o/\alpha^{b_o} + \left[14.42_1/\alpha^{b_1}\right] \cdot \exp\left(0.000643(\theta^2-225)\right)$, $\theta > 15; \alpha \le 9.1$ $a_o/\alpha^{b_o} + \left[14.42_1/\alpha^{b_1}\right] \cdot \frac{690}{\alpha}\left(0.0001486(\theta^2-225)\right)$, $\theta > 15; \alpha > 9.1$	1.00	0.32

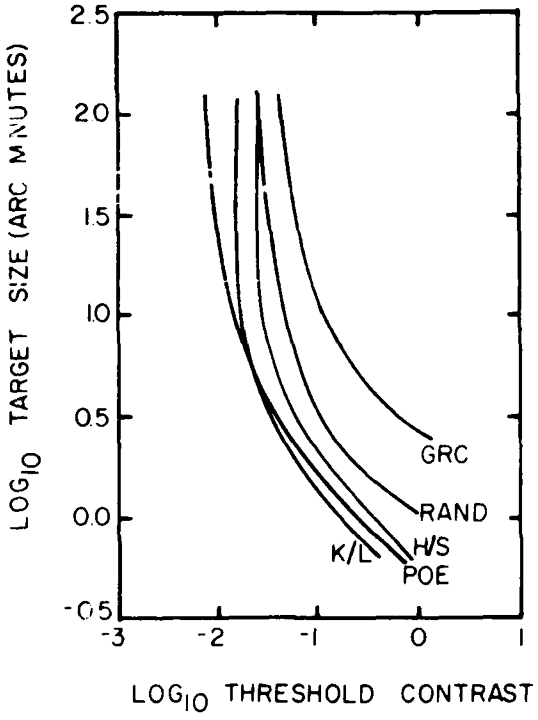

Figure 53. Foveal threshold contrasts as predicted by the five candidate models (3).

Four parameters of the models were fit to the field test data:

1. A multiplying field factor for contrast;

2. Frequency-of-seeing curve standard deviation;

3. Frequency-of-seeing curve truncation point (relative contrast value corresponding to zero detection probability); and

4. The target size for transition from H/S to GRC; an initial value of 2 min was used.

Observers searched a 60 deg (horizontal) x 30 deg (vertical) field with no instructed search pattern.

The H/S model yielded parameter values of 1.33 as a multiplying field factor (FF) and σ = 0.24 for a nontruncated frequency-of-seeing curve. The resulting cumulatives are given in Figure 55, which indicates an average square error (ASE) of 0.009 between the model and the actual data. This field factor may be explained as a "standard" correction for uncertain occurrences of the target.

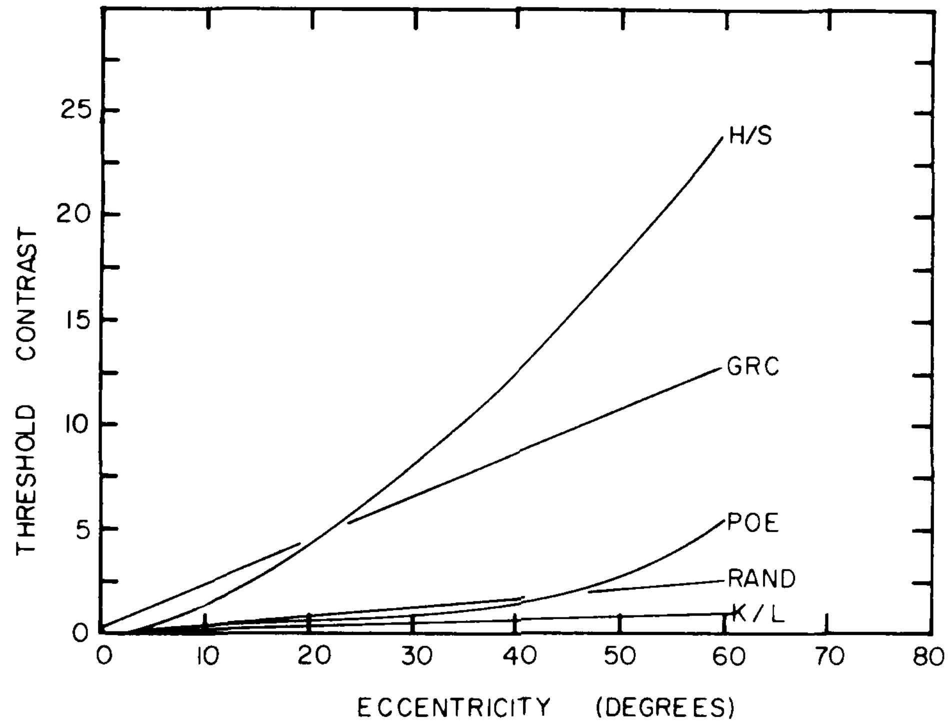

Figure 54. Peripheral threshold contrasts for 3.6 arcmin targets as predicted by five candidate models (3).

The composite GRC-Hammill/Sloan also yielded 1.33 FF for H/S with σ = 0.24 and a target transition size of 2.24 min, while GRC yielded no FF with σ = 0.42 and truncation at C/C_t = 0.015. The ASE of the curves was 0.007. The composite model may thus be a suitable alternative to the H/S model.

The H/S model yields the following expression of contrast threshold with the field factor of 1.33:

$$C_t = 0.0352\,\theta^{0.24} + 0.584\,\theta\,(1.6/\alpha^2),\quad (\theta \geq 0.8 \text{ deg}) \qquad (13)$$

A partial validation of this resulting VIDEM model was attempted for seven individual profiles, consisting of at least 60 detection events each. All previously considered models are depicted in Figure 56. It can be seen that the GRC model consistently predicts slowly, while the Koopman/Lamar version is always too fast. A mean detection range difference of more than 11 kilometers is manifested between the K/L and GRC predicted values.

TABLE 18. PERFORMANCE MEASURES OF BEST VERSIONS OF FIVE CANDIDATE DETECTION MODELS IN PREDICTING COCO AND K&W SEARCH EXPERIMENTS (3)

MODEL	BEST VERSION		TARGET SIZE (ARC MINUTES)						
	FF	σ	2.0	4.0	4.8	8.0	13.0	24.0	46.0
K/L	NO B	0.25	++	++	++	++	++	+	0.59
H/S	--	0.25 OR E	1.00	+	+	++	+	1.00	0.71
RAND	--	0.32 (NO T)	+	+	+	+	+	0.97	1.00
GRC	--	0.39 (NO T)	-	0.90	1.00	0.47	0.00	0.00	0.47
POE	5.5	0.32	=	-	1.00	0.00	0.29	0.16	0.00

Key: FF Field Factor (usually as a contrast threshold multiplier)

NO B Seyb luminance factors not used

E Koopman empirical curve

NO T Frequency-of-Seeing curve not truncated

Note: Numerical performance measures are Kolmogorov-Smirnov probabilities.

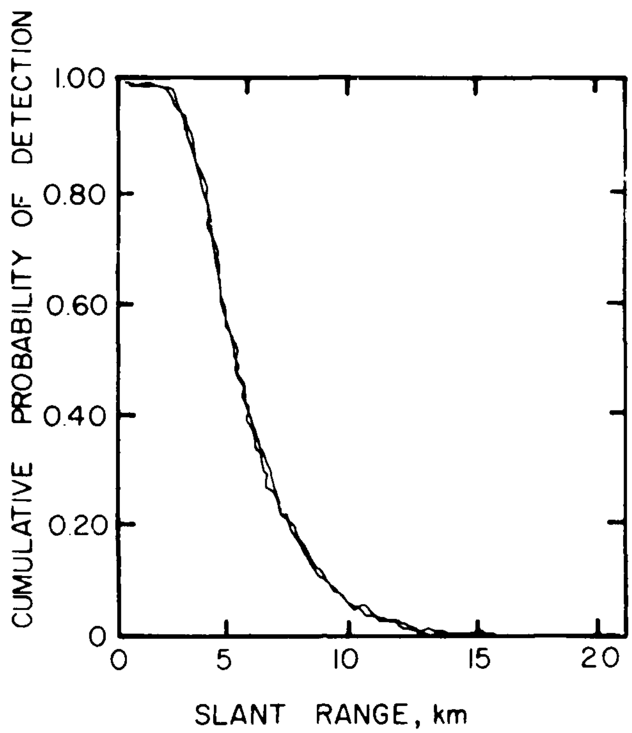

Figure 55. VIDEM-predicted and actual field test cumulative for all data (3).

The Unstructured Field

The air-to-air acquisition problem often becomes one of search and detection in the unstructured or empty field. The behavioral and visual aspects of such a search situation are described above. The modeling implications range from determining the proper expression describing the glimpse pattern of an observer to the reduced detection distance that results from the absence of structure in the search field.

The models of both Erickson and Burge (76) and Akerman and Kinzly (3) address this question and utilize the assumption of independence of glimpses which is equivalent to a random search pattern. This assumption was first introduced by Koopman (129) in his treatment of air-to-sea search which may indeed be unstructured, but does not resemble an empty-field as such. Thus, Erickson and Burge (76) use a correction factor of 1/2 to adjust laboratory data to the detection range of the empty field. Akerman and Kinzly (3), however, do not mention such a correction, although their model is designed to describe performance in the unstructured field. They utilize a soft-shell search model and appropriate data bases to account for acquisition against

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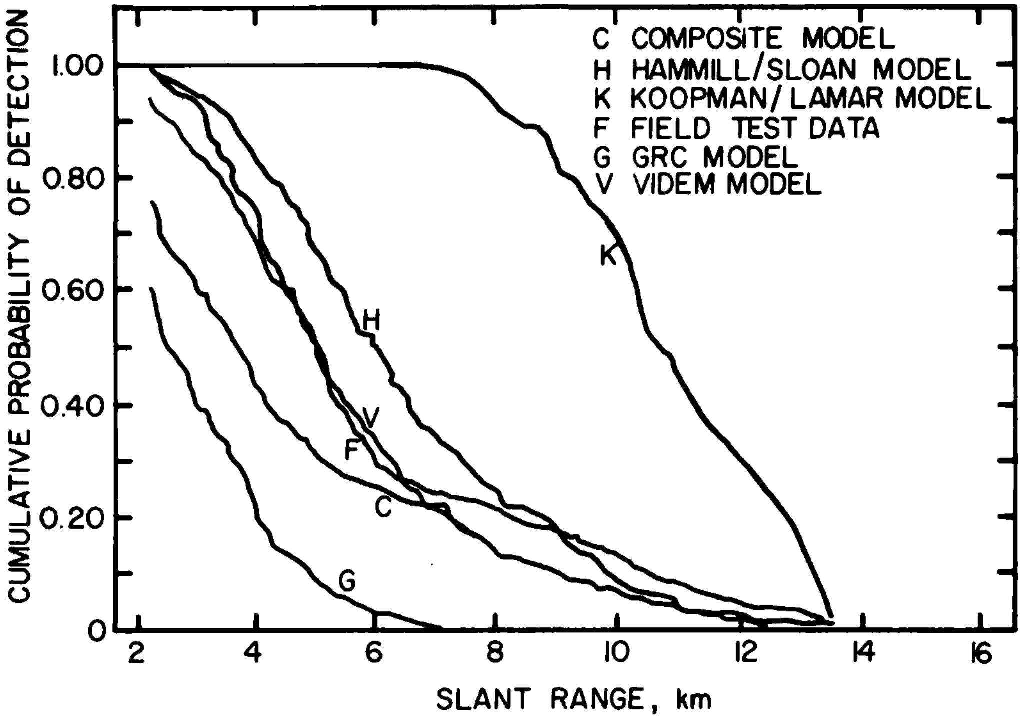

Figure 56. Actual cumulative detection probability of the 900-meter altitude profile as predicted by the various models (3).

the sky background, but it is unclear whether this is, in fact, the empty field case.

The classic study of search in an unstructured field was conducted by Krendel and Wodinsky (134) in which time to detection was measured for various combinations of target size, search area, and background luminance for contrast values at least twice the 95% threshold. It was found that mean time to detection is independent of target position in the field, with no practice effects at the 0.05 level of significance. Moreover, there was strong but not conclusive evidence that the exponential distribution described the experimental search process (with or without alerting signals). It is concluded that the exponential distribution is generally adequate when: (1) the search time is limited to about 30 s, (2) the variables remain fixed during a trial, and (3) no instructions or search strategy are employed.

The basic assumptions of Krendel and Wodinsky (134) have since been questioned by several researchers. In a study investigating the visual search process, Williams (230) concludes that detection probability in the air-to-ground context is a function of rate of scanning and target conspicuity. He postulates that search is systematic with random components. (He goes on to set up an interesting equality in which the number of scans is given by: $T/t_{ss} = C/R$, where T is total time, t_{ss} is single scan time, while C and R refer to conspicuity and scan rate, respectively.)

Perhaps in the air-to-air case, search becomes random with systematic components. This would be consistent with the general finding that the ability to search systematically or to scan with regular patterns increases with the degree of structure to the search field. As the field becomes very structured, even a systematic pattern may not yield efficient results due to confusion and breakdown of orderly scan patterns generated by a complex background.

In another study (Howarth and Bloomfield, 111) dealing with structured backgrounds, it was concluded that search time distributions are not well described in terms of mean search times. However, they present formulations of the probability of detection after a given time for either random or systematic search with a constant single glimpse probability, P_s. These are essentially similar to those proposed by Krendel and Wodinsky. Thus, efficient search after n fixations yields $P_n = nP_s$, whereas searching randomly will result in $P_n = 1 - (1 - P_s)^n$. The mean number of fixations, $\bar{n}$, for regular search is given by $\bar{n} = 1/2\ (1/P_s + 1)$, while it is expressed as $n = 1/P_s$ for random searching.

Krendel and Wodinsky considered the random model to be expressible as:

$$P(t) = 1 - e^{-mt} , \qquad (14)$$

where m $-P_{sg}/T$ and t equals glimpse time, while T equals total search time for $P_{sg} << 1$. Otherwise,

$$m = - [\ln (1 - P_{sg})/T]. \qquad (14a)$$

By comparison, the expression describing an ideal pattern of search with no overlap was given by $P_i(t) = (P_{sg}t)/T$, which becomes unity after a time, t, equal to T/Psg.

In his formulation of air-to-ground models for the RAND Corporation, Bailey (9) presents random and systematic alternatives of the detection probability function. The systematic search version is characterized by a ramp function given by

$$P_i = 3\ t/(A_s/A_g) , \qquad (15)$$

where P_i refers to the probability of foveally fixating the target for 1/3 s duration, while A_s is the area searched and A_g is the useful glimpse area, i.e., $A_g = kA_t$ in which A_t is target area, k is a factor of scene congestion, and 3 is the available number of glimpses per second.

Although Bailey considers real search to lie somewhere between the perfectly systematic and the purely random extremes, he nonetheless chooses the exponential function to more accurately describe the initial use in detection probability in the purely random case. This is given as:

$$P_i = 1 - e^{-k \cdot 3t(A_s/A_g)} \quad . \qquad (16)$$

In general, Bailey considers the observer to search with a fairly regular pattern and an adaptive search rate until there is a perception of an area of contrast having the target's specifications, at which time detection occurs.

In summary, it seems reasonable to conclude that the assumption of random independent glimpses and the accompanying exponential distribution tend to adequately describe the probability of detection in the completely unstructured field. As reference points are introduced into the field, the observer may tend to utilize some sort of strategy or search pattern. Moreover, the problem of detection at threshold conditions that may be required to avoid a collision or intercept an enemy aircraft is compounded by the myopic state induced by the purely empty field. In the empty field, a target must be larger and thus closer before detection may occur.

The Structured Field

Although structure initially appears to aid the observer to systematically cover the area to be searched, too much structure may become clutter which leads to problems of discrimination as well as detection. The air-to-air environment seldom exhibits the problem of too much clutter, although situations in which more than one target in the field of view may arise, especially in landing patterns or other areas of high density traffic.

Since search time varies directly with angular range of the search sector (41) even the observer who employs a systematic pattern of search is limited by the extent of the field that must be covered. In the case of an area of dense aircraft traffic, this can be a serious problem.

It is reported by Andrews (4) that unalerted pilots tend to concentrate their glances within 30 deg of straight ahead, yet will spread these glances out more evenly over the entire visible area if informed to be on a collision course. Once warned, it is assumed that the pilot's glances will be uniformly distributed over the area indicated. Andrews proposes that one good method to further "structure" a partially structured field is with a Pilot Warning Indicator (PWI) which basically tells the pilot in which direction to look.

The major purpose of Andrews' (4) report was to demonstrate the degree of improvement offered through the use of a PWI system. A series of flight tests was conducted by the MIT Lincoln Laboratories to determine the relative effect of being alerted on a pilot's acquisition performance, compared to the unalerted case. Several different aircraft were employed at various closing rates and aspects or crossing angles (difference in headings). The results of one particular encounter situation are shown in Figures 57 and 58. For the unalerted case, the curves indicate that unaided visual separation can be effective only for the smallest crossing angles. This is due to the increased closure rates and decreased visible areas associated with larger crossing angles. In the alerted case, however, it was found that acquisition was improved by a factor of nine. It was also found that large jet aircraft were acquired at greater ranges than smaller aircraft, which compensated for the disadvantages due to increased closing speed. However, large speed differences increase the probability of a tail-chase encounter in which there is only a 77% chance of acquisition with 15 s to collision. This is shown in Figure 59.

Andrews (4) goes on to consider the case of two searching pilots. This is generally the situation when two aircraft are on a collision course, in that both pilots are concerned with collision avoidance and hence early acquisition. Andrews states that the effective acquisition rate for either of two pilots is simply the sum of the rates of each pilot separately. When an aircraft structure acts to obstruct the view (as when the faster craft is approaching from the side opposite the pilot), the situation reverts back to the single pilot case. The presence of additional searchers such as copilots will alter the acquisition rate according to this additive principle.

Although the effectiveness and utility of PWI devices was the intended focus of the Andrews (4) report, the simplified model he employs to describe the acquisition process is worthy of further treatment. Andrews postulates that acquisition is a random process that can be complctely characterized by an acquisition rate, $\lambda(x)$, equivalent to the probability of acquisition per unit time. The acquisition rate is a function of a vector $x(t)$, with k components that affect performance, while acquisition itself is a heterogeneous Poisson process. Such a process assumes that arrival rates are not constant and that the first arrival event terminates the trial with an acquisition.

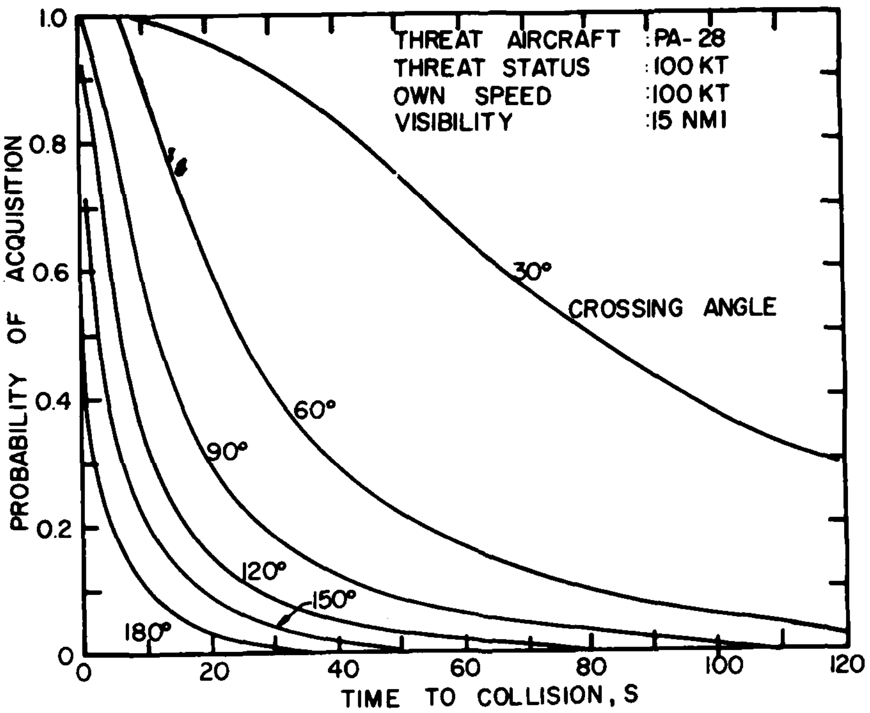

Figure 57. Predicted acquisition performance for unalerted search by single pilot (4, p. 43).

The conception of acquisition as a continuous process permits the use of a time-averaged rate which need not consider the duration of a single glimpse.

Starting with a cumulative probability of acquisition denoted by F(t), and the related probability density function given by $f(t) = dF/dt|_t$, Andrews derives an expression for F(t). Thus,

$$F(t) = 1 - \exp(-\eta) \ , \qquad (17)$$

where $\eta = {}_\infty\int^t \lambda(\xi)d\xi$, whereby $f(t) = \lambda(t) \exp(-\eta)$. In general, the quantity η of a Poisson process is the expected number of arrivals occurring by time t.

It is further presumed that the k variables upon which acquisition depends can be identified. Acquisition can then be modeled as a linear function of those variables, expressed as

$$\lambda(x) = \sum_{i=1}^{k} \beta_i X_i \ . \qquad (18)$$

The individual pertinent variables, X_i, though not necessarily linear in themselves, are weighted by the β_i values

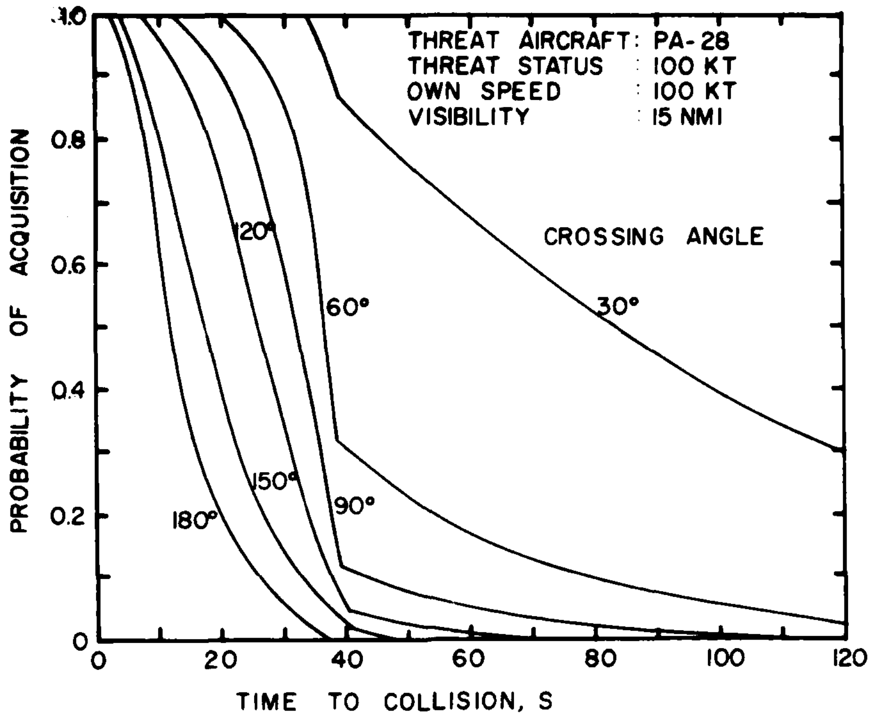

Figure 58. Predicted acquisition performance for PWI alert at 40 s to collision (single pilot) (4).

based on conditions, and treated additively to determine acquisition rate.

Based on the data of an experiment conducted by the Control Data Corporation (Millhollon, Lyons, and Graham, 165), Andrews (4) was able to demonstrate, by a method of maximum likelihood estimation for the β_i values, a dependence of acquisition rate on target range. Range to target thus emerged as one of the X_i to be included in the model.

Figure 60 indicates the relation between acquisition rate and range for a given encounter situation. A curve of the form β/r^2 closely depicts the data. Andrews therefore contends that the term β/r^2 represents the product of contrast and size suggested by Lamar et al. (137) to be primarily responsible for the detectability of targets. In this case, β takes on a value of 0.13, but will take on different values for different circumstances.

Results of flight tests conducted at the MIT Lincoln Laboratory during 1975 and 1976 were used in a similar fashion to determine the additional dependence of λ on the visible area of the target. Andrews therefore concludes that acquisition rate is primarily dependent upon the solid angle of

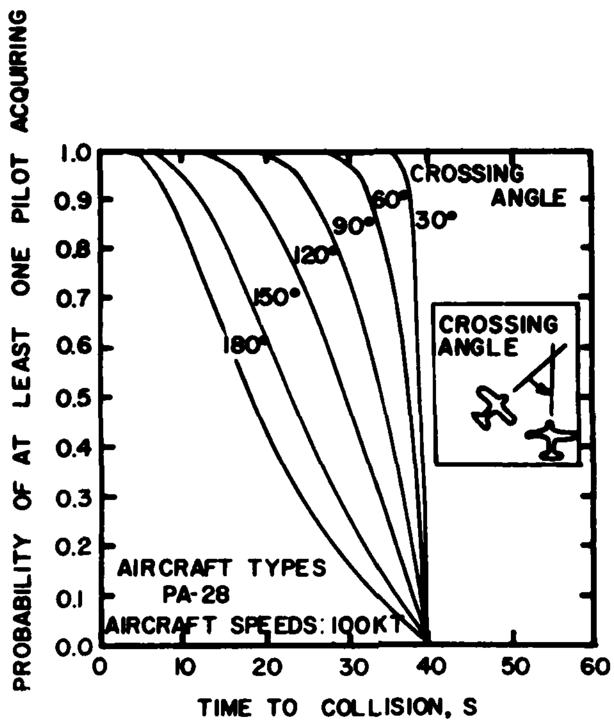

Figure 59. Probability of acquisition by either pilot (two small aircraft, alerted search beginning at 40 s to collision) (4).

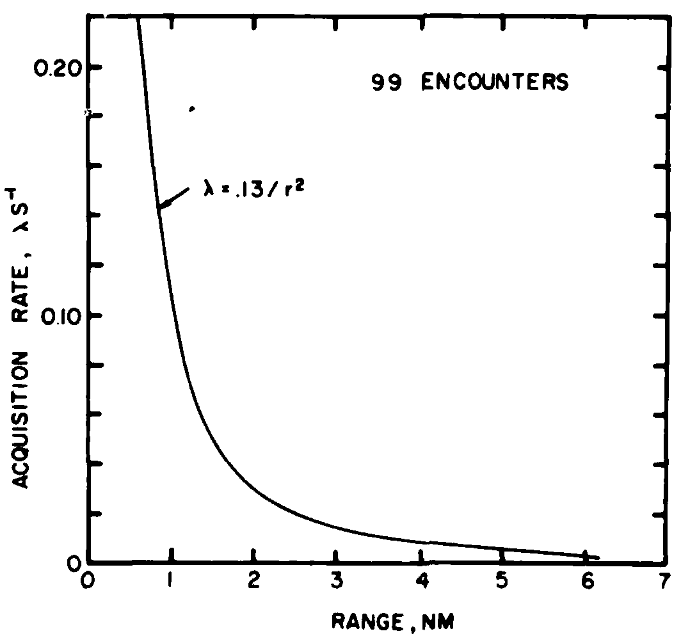

Figure 60. Acquisition rate for detection of Beech Musketeer (4, p. 19).

the target which is indeed the ratio of target area to target range squared, i.e., $\lambda = \beta A/r^2$. This relation between λ and solid angle of the target is considered by Andrews to be linear in nature and to sufficiently describe acquisition rate.

Since the value of β varies with conditions, formulations are presented which adapt the model to various contexts. Modifications due to fractional search time are accomplished by multiplying the parameter β_o for constant search by the fraction, k, during which the pilot is actually searching. A modification due to differing subjective search areas, S, for a given PWI search sector capacity, S_o, is given as the ratio S_o/S. The effect of the atmosphere in reducing contrast is presented according to the standard exponential contrast reduction factor $\exp[(-3.92\ r)/V]$ where V is visibility. Thus, acquisition rate for various conditions is expressed as:

$$\lambda = (k)/(S/S_o)\ \exp(-3.92\ r/V)\beta_o\ (A/r^2). \qquad (19)$$

The concept of acquisition rate was also proposed by Bradford (39) of Sandia Laboratories, based on the assumption that the rate of target acquisition of an observer follows a gamma density function given as:

$$\gamma(t) = f(t)/[1 - F(t)]\ . \qquad (20)$$

Bradford's cumulative probability of detection is thus expressed as $F(t) = 1 - \exp(-\int_0^t \gamma(x)dx)$, which is essentially identical to the formulation of Andrews. However, the acquisition rate of Andrews is empirically derived at the outset by partitioning the experimental search field into range intervals during which acquisition rate is determined by dividing the total number of detections in an interval by the time in that interval.

In summary, the problem of acquisition in the structured field is generally one of suprathreshold detection which must occur somewhere in the field of view with sufficient time to respond. Acquisition performance is thus improved through reducing the size of the search field, thereby improving the efficiency of otherwise random search processes. An improvement in acquisition performance will, of course, occur with increasing target size, but this is at the expense of time to react. Moreover, it would seem possible that when some degree of structure is present in the air-to-air environment, a systematic scanning procedure to encompass the entire search field might be utilized. Such procedures should thus contribute to improved acquisition. However, aside from the search cycle concept of Short (195), which implies a non-overlapping pattern to search, the models considered in the discussion above have no provision for such systematic search techniques. Opportunities for model improvement seem to exist here.

Evaluation of Air-to-Air Models

Establishing a set of criteria that could be used to evaluate the utility of various models derived from different standpoints and developed for somewhat different purposes is a difficult task. In the reviews by Greening (90, 91) of the air-to-ground modeling field, an attempt at evaluation was abandoned in lieu of a comparison of the outstanding models along a common set of criterion-like measures. The measures used by Greening are quite general and are therefore applicable in the air-to-air modeling context as well. Several of these criteria were chosen for the present evaluation:

1. Incorporation of significant quantities,

2. Nature of model output,

3. Range of applicability, and

4. Evidence of validity.

As mentioned earlier, the significant quantities of target acquisition are essentially those target and scene characteristics and geometries, as well as observer characteristics previously discussed in the sections "Stimulus Characteristics" and "Observer Characteristics."

The major models to be assessed in the present context include the formulations of Short, Erickson and Burge, Andrews, and Akerman and Kinzly. The parameters considered to be significant to this evaluation include target size, target offset, scene luminance, target/background contrast, type of search sector, search representation and search technique, relative motion, and glimpse time, as well as workload (alerted versus unalerted case), masking (structural limitations on the field of view), and the visual acuity of the pilot.

A data matrix is presented in Table 19, in which the four air-to-air models chosen for evaluation are compared along the significant parameters listed above. The pertinent information was obtained from the material previously cited. Where a mathematical expression was lacking, a descriptive remark is supplied.

We might start by noting the omission of observer characteristics such as visual acuity and other sources of human

TABLE 19. OVERVIEW OF AIR-TO-AIR MODELS

PARAMETERS	SHORT	E/B
TARGET SIZE	$\alpha_t = 1293\ A^{1/2}/R$	A/R^2
OFFSET	$C_R = 1.75\theta^{1/2} + (19\theta/\alpha_t^2)$	$C = 1.75\theta^{1/2} + \frac{45.6\theta R^2}{A}$
FIELD LUMINANCE	Daylight Conditions	Daylight Conditions
CONTRAST	$C_o = \frac{B_o - B'_o}{B'_o}$	$C = \frac{L_B - L_T}{L_B} \times 100$
(APPARENT)	Atmospheric Attenuated Factor, $e^{-\sigma R}$	$\sigma = \frac{-3.912}{V*}$
TYPE SECTOR	Structured-Warning Unstructured-No Warning	Regular Empty
(SEARCH REPRESENTATION TECHNIQUE)	Visual Lobe Uniform Glimpses	Visual Lobe Random
RELATIVE MOTION	Collision Course	Moving Target
GLIMPSE TIME	Search Cycle Glimpse, T, = 1.5 sec.	1.65 sec.
WORKLOAD	Alerted Observer Unalerted Pilot	No Provision
MASKING	No Provision	No Provision
ACUITY	Normal	Normal

* V=Visibility

TABLE 19 (Continued)

PARAMETERS	ANDREWS	VIDEM (A/K)
TARGET SIZE	A/r^2	A/R^2
OFFSET	Reduces Probability	$C_T = .0352\theta^{.24} + \frac{.584\theta^{1.6}}{\alpha^2}$, (for $\theta \geq .8^\circ$)
FIELD LUMINANCE	Daylight Conditions	Daylight Conditions
CONTRAST	$C = \frac{L_B - L_T}{L_B}$	$C = \frac{\lvert L_T - L_B \rvert}{L_B}$
(APPARENT)	$\sigma = \frac{-3.912}{V^*}$	$\sigma = \frac{-3.912}{V}$
TYPE SECTOR	Structured-Warning Unstructured-No Warning	Unstructured (Others)
(SEARCH REPRESENTATION TECHNIQUE)	An Acquisition Rate: a/S_T Uniformly Random	Soft-Shell: $P(\theta^1)$ Uniformly Random
RELATIVE MOTION	Collision Course	Quasi-Static Provision for Moving Target
GLIMPSE TIME	Not Considered	3 Glimpses/second
WORKLOAD	Alerted Unalerted-Fractional Search Time	No Provision
MASKING	% Obstructed FOV Considered	No Provision
ACUITY	Normal	Normal

* V=Visibility

variability from the models. This was indeed the case with air-to-ground models, as reported previously (Greening, 90). It is thus standard to assume the observer to be highly motivated, vigilant at the task, and well trained, although no particular form of training is specified.

Generally speaking, the parameters related to the characteristics of the external scene in which the object must be detected are similarly described in the models now under consideration.

These same stimulus characteristics, such as target size, position, and contrast threshold, were included in the previously discussed air-to-ground models and represent the various data bases compiled primarily from the results of psychophysical experiments. The expression for target/background contrast and the attenuation due to the intervening atmosphere are the same for each model while only the conditions of daylight luminance are considered.

The empty field is provided for in the Erickson and Burge (E/B) model, while the Akerman and Kinzly (A/K) model is formulated specifically for the unstructured field. The models of both Short and Andrews provide "structure" to an otherwise unstructured and larger field through the concept of the alerted pilot and the aid of the Pilot Warning Indicator (PWI) device. The models of Short and of Erickson and Burge utilize the visual lobe concept to represent the means of determining probabilities of detection during search. Andrews develops the notion of an acquisition rate equivalent to the target area divided by a unit search area, while Akerman and Kinzly propose a soft-shell approach. Both of these models employ a probability density function, $P(\Theta)$, which is defined over the search area.

Moreover, the assumed search technique of the observer for each model is that of random glimpses uniformly distributed over the field of search. The glimpse times used in the models are essentially similar to each other with the exception of the Andrews model, which deals with "average" acquisition. Furthermore, only the Andrews model has a provision for the masking of the field of view due to aircraft structure, while the Akerman and Kinzly model is derived for the quasi-static case with some provision, however, for target motion.

The outputs of the various models generally include the single glimpse probability and the cumulative probability of detection. The Short model yields the probability of target detection for any selected range out to maximum range from the equation,

$$P_o(R) = 1 - \exp 1/VT \int_{R}^{R_m} \ln(1 - G)dR \, . \tag{21}$$

Erickson and Burge propose a similar equation for cumulative probability of detection after n glimpses,

$$P_n = 1 - \exp 1/\Delta R \int_R^{R_m} \ln(1 - g_i)dR \quad , \tag{22}$$

while the single glimpse value, g_i, is given from the search geometry as discussed earlier:

$$g = \Theta^2/[(H + \Theta)(\phi + \Theta)] . \tag{23}$$

This is the same expression used by Short for single glimpses.

Akerman and Kinzly utilize the frequency-of-seeing curve, $g(\alpha,\Theta) = \phi[(C/C_t - u)/\sigma]$, together with the expression $g = \int p(\Theta') g(M\Theta') d\Theta'$, where $p(\Theta')$ is a probability density function for all angles in the search field, to compute single glimpse probabilities. The value of g is used in turn to compute cumulative probabilities after n glimpses from the equation $P_{cum}(n) = 1 - \exp[\sum_{i=1}^{n} \ln(1 - g_i)]$.

This final formula is essentially identical to the other cumulative probability formulations just presented.

Although the outputs of Andrews' model are these same probabilities of detection, i.e., single glimpses and cumulative, the expressions derived are based on his concept of acquisition rate, or the average number of detections for a unit of time. Thus, the instantaneous probability of detection is given by

$$f(t) = F/dt = \lambda(t) \exp [- \eta], \tag{24}$$

where (t) is acquisition rate, and $n = {}_{-\infty}\int^{t} \lambda(\xi) d\xi$. The cumulative probability is then expressed as

$$F(t) = 1 - \exp[- \int_{\infty}^{t} \lambda(\xi)d \xi] . \tag{25}$$

Some of the major limitations on the range of applicability are similar to those noted for the air-to-ground models. These include no provision for observer characteristics, as mentioned, with no correction for glare and little provision for masking or workload. Moreover, the air-to-air models considered are all limited to the conditions of daylight viewing.

As noted by Greening (90) in his report on air-to-ground models, establishing the validity of a complex process is enormously difficult. The validity of a model may be thought of as the degree to which the model actually describes the process it intends to describe. Therefore, validity must be established by correlating the predictions generated by a model with actual performance measures from a corresponding real-world context. Moreover, a determination of validity is aided by a large number of data points for each condition. This process can become very expensive, as has been noted earlier. Furthermore, it is extremely difficult to control the external conditions during a field trial.

Consequently, many of the models presented in this report are only partially validated, at best. When model predictions do not match field data, there is a general tendency to apply "field factors" to adjust the data to the theory rather than to revamp the model itself.

Among the air-to-air models presently considered, only those of Andrews and of Akerman and Kinzly have been subjected to field trials in an effort to establish validity. Although Andrews does not directly address the evaluation of validity, he does establish a close correspondence between flight test results and his simplified model of acquisition based on an inverse square relation with target range (Figure 60). Akerman and Kinzly, however, do address the question of validity by registering the final parameterized version of the VIDEM model with at least 60 detection events. Although the results listed in Table 20 indicate that the VIDEM model provides a better prediction than the Hammill/Sloan model, it was noted that VIDEM underpredicts for altitudes below 900 meters and overpredicts for higher altitudes. Akerman and Kinzly thus conclude that rather than further refining their model, it might be more fruitful to generate confidence limits which would indicate how much variability might be expected between prediction and reality. In summary, it appears that even the most sophisticated of the models provides only an approximation of the visual acquisition task. These models, nonetheless, serve an essential function by acting as a point of reference for future research and systems design.

TABLE 20. DIFFERENCE IN MEDIAN DETECTION RANGE BETWEEN FIELD TEST RESULTS AND MODEL PREDICTIONS (3)

MODEL PREDICTIONS

Profile		Range Difference (m)	
Altitude (m)	Offset (m)	VIDEM	Hammill/Sloan
300	1500	- 90	910
300	0	-1280	- 640
300	-1500	-1100	- 90
900	0	0	1000
1500	1500	180	1000
1500	0	820	1830
1500	-1500	640	1650

AREAS OF POSSIBLE IMPROVEMENT

Training

The effects of training on an observer's ability to detect and identify targets in a search situation have been examined by a number of investigators. The most emphasis has been placed on air-to-ground search, and many researchers have looked at individual facets of the problem, such as type of instruction, peripheral acuity, search pattern, and others.

Visual acuity may be improved with training, although the training should be in the style of repeated practice. Low (146) reported an improvement in peripheral acuity with practice, but it is very slow. Improvement required long continued practice, forced fixations, unlimited viewing time, and stationary test objects.

Ludvigh and Miller (147) and Miller and Ludvigh (164) both report that dynamic visual acuity (DVA) improves with repeated practice (Figures 61 and 62). They report that DVA improves at a greater rate for higher target velocities, where DVA ordinarily tends to be worse. This improvement takes place fairly rapidly, quite often in less than 20 trials. Because this improvement seems to be significant in magnitude and occurs fairly rapidly, it would seem worthwhile to include some repeated training trials on a DVA-related operational task to get this improvement in DVA. The retention of this improvement in DVA over time has not yet been examined.

Baker and Steedman (13) examined a task involving visual estimates of closure rates. They specifically examined subjects' estimates of relative distance traveled by a luminous object approaching on a collision course, and viewed in an otherwise homogeneous field. Subjects demonstrated a considerable reduction in error with training at estimating the halfway point of approach (Figure 63). The training was in the form of repeated trials with knowledge of results after each estimate.

McCluskey et al. (152) also found an improvement in range estimation skills with training. They examined three types of estimation methods in training:

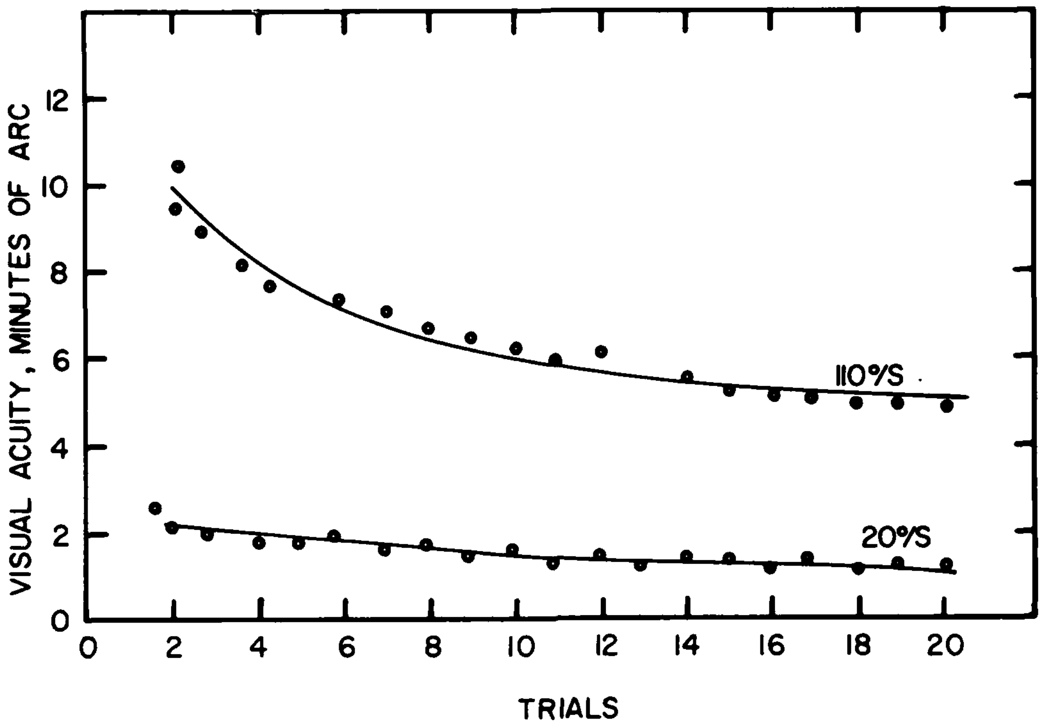

Figure 61. Effects of practice on dynamic visual acuity (147).

1. Paired associate--the range of the aircraft would be announced, and the subjects were to try to remember the aircraft's appearance;

2. Finger occlusion--the aircraft's range was announced, and the subjects were to remember how much of the aircraft was observed by a finger held at arm's length; and

3. Immediate reinforcement--the subjects wrote their range estimates down and were then told the correct ranges.

All three methods led to an improvement in range estimation, but no significant differences were found among the three methods.

Vicory (216) summarizes previous and current methods of aircraft identification training. The WEFT system involved the commitment to memory of various characteristi s of the wings, engines, fuselage, and tail. One of the difficulties of this procedure was its overemphasis on aspects of aircraft shapes that could be named easily (i.e., taper, swept back, etc.) and neglect of other aspects not so easily

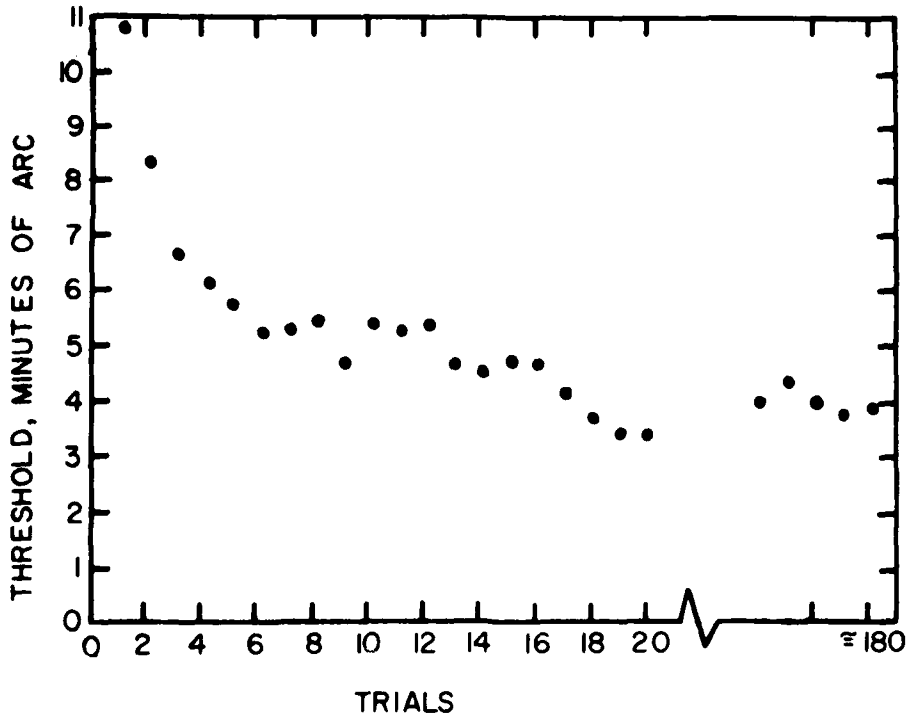

Figure 62. Effect of prolonged training (147).

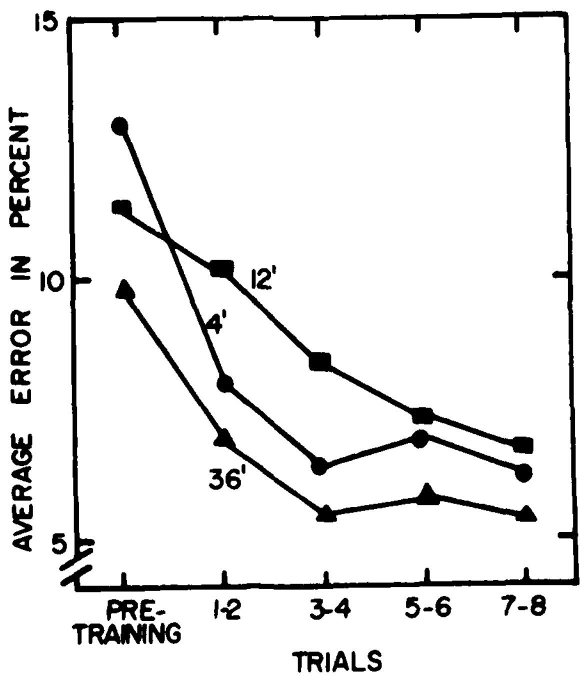

Figure 63. Average deviation of total distance as function of training trials for three angular sizes of stimulus (13).

named. The learning tended to be verbal in nature--a list of characteristics. Much of this verbal learning was unsystematic and arbitrary. This system presented silhouettes of bottom-view, head-on view, and side-views only.

The Renshaw system used brief exposure (1/75 or 1/100 s) of the aircraft on a screen until the trainee was able to identify it. This placed an emphasis on whole-image learning, as opposed to the image-analysis idea of WEFT.

This system was not really appropriate, however, as brief glimpses of aircraft were very unlikely. There always was plenty of time to identify the aircraft after detection.

Of the two systems, the WEFT allowed more subtle differences in aircraft shapes to be detected, and led to better recognition than did Renshaw.

Training in this type of skill becomes pertinent only after detection of an approaching aircraft. In a study of visual discrimination (Taylor, 206), it was found that subjects' discrimination performance had reached a fairly stable level (Figure 64) at the 1000th trial. No further improvements in performance were found out to the 50,000th trial.

Taylor (207), in looking at a visual detection task, found that short-term practice effects (most likely due to familiarization with surroundings and habituation) are followed by gradual long-term reductions in detection threshold. The curve produced by these long-term improvements had a very low slope, and there is high variability in these reductions. This variability may limit the usefulness of this type of training due to the slow improvement of trainees.

Thornton et al. (213) demonstrated significant correlation between field independence and amount of time needed to locate an aerial target ($r = -0.66$, $p < 0.001$). They also point to the possibility of developing differential training procedures to expedite the learning of target detection based upon the degree of field independence of the trainee.

Howarth et al. (110) noted that continued practice considerably improves search performance and reduces search time.

The possibility may exist of increasing search efficiency by reducing fixation times (201) or making quicker saccades (117). Although Jones says that fixation times can be trained, he provides no clue as to what procedure or method may be effective. Presumably, by decreasing fixation time, the observer will be able to search more of the field in a

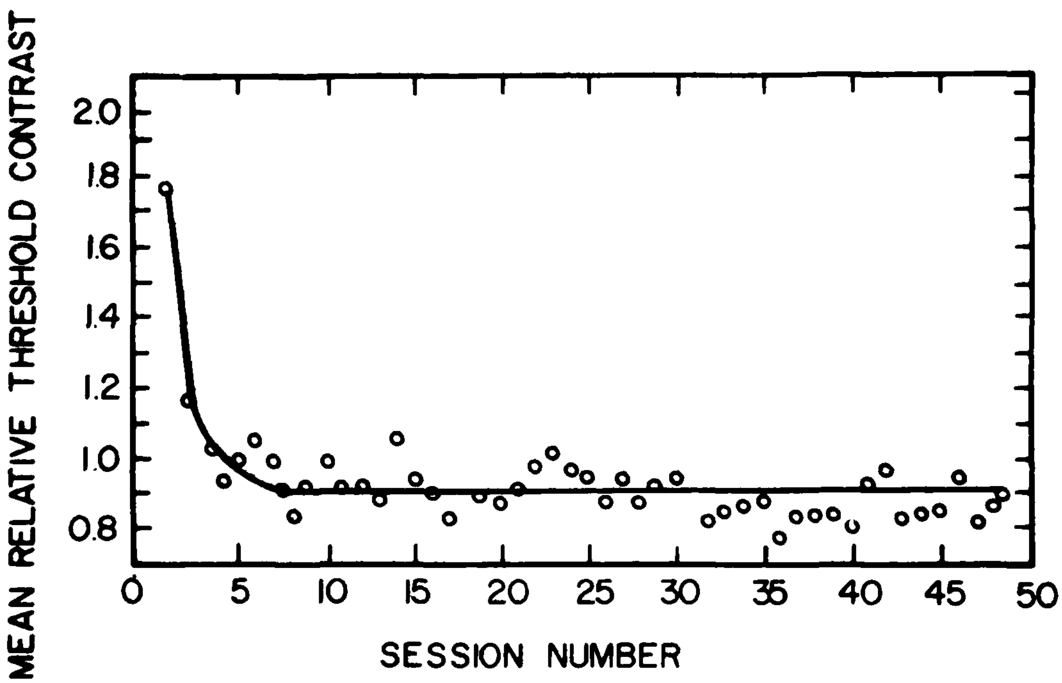

Figure 64. Average practice curve from four initially naive observers over 50 experimental sessions (206).

shorter time, which would lead to superior target acquisition performance.

In examining search in an unstructured visual field, Krendel and Wodinsky (134) found no significant practice effects ($p < 0.05$) in search performance.

In an air-to-ground search situation, Hansen and Wright (100) developed an experimental design for evaluating different training procedures. They used two levels of training content, differing in amount of material drawn from perceptual theory; two levels of target signature characteristics, explicit definition versus comparison of similar target objects; and two levels of display dynamics, static slides or motion pictures.

Hansen and Wood (99) conducted an analysis of the design set up by Hansen and Wright (100). They found that instruction in visual system theory produced more positive training effects than instruction in visual performance principles (emphasizing psychophysiological reasons for good visual performance rather than dos and don'ts). They also found that static training produced better performance than dynamic treatment and noted that instruction based upon explicit definition of target signature characteristics was more effective than instructions based on comparisons of similar target objects (implicit definition).

In another examination of air-to-ground search, Thomas (211) found that observers who had received training in the form of instruction in the use of the side movement (looking to the side of the aircraft and moving the head from side to side) search method had better search performance than observers instructed in any other method.

Thomas and Caro (212) found that observers trained in the same side movement search method performed better at each of three aircraft speeds in a low altitude visual observation task. The training consisted of a brief introduction to visual search, including objectives, then classroom instruction and practice in the type of movement to be used. The tendency to "lock-on" (the detection of one target causing the missing of others) to sighted targets was emphasized as a procedure to be avoided.

More recently, Ginsburg (personal communication) has had success in lowering contrast sensitivity thresholds through training. While much research needs to be done in this area to determine the stability of such improvements, there seems to be some promise for improvement of detection by increasing sensitivity at the high spatial frequencies.

Search performance can be improved through training, as indicated by the results of Thomas and Caro (212). In an unstructured field situation, other training techniques may be required. For example, Overby (174) demonstrated that training with search uniformity feedback resulted in more uniform coverage and improved search performance. Overby monitored eye movements and displayed to his subjects, after each 10 trial block, the display areas not receiving adequate search coverage. Subjects trained under an adaptive training regime improved faster, to a higher asymptote, than did (1) subjects trained on a fixed regime, or (2) control subjects.

In summary, training techniques show promise to (1) improve peripheral acuity, (2) possibly improve foveal acuity, (3) improve dynamic visual acuity, and (4) improve search field uniformity of coverage.

Selection

It may be possible, in areas where visual search is a necessity, to improve performance through the initial personnel selection phase. This may be done by examining possible individual differences of the observers.

Because of the importance of peripheral vision in search situations, it would be worthwhile to administer a test to determine the size of the prospective observer's peripheral field, and select those with larger peripheral fields for continuation through training.

Peripheral acuity also plays a large role in visual search situations. Erickson (71) found that peripheral acuity correlates significantly with search time. Selection on the basis of peripheral acuity may be a useful concept.

Davies and Tune (54) state that present evidence suggests that younger people perform better on detection tasks. This may be because the size of the visual field begins to shrink after approximately age 35 (see Figure 24).

Davies and Tune (54) also say that there is no evidence of a relationship between level of intelligence and target detection ability. However, intelligence may still be a worthwhile basis for selection. If the observer is in a situation where he has competing tasks, level of intelligence may have a significant correlation with the ability to carry out all the aspects of his task. It is unlikely, however, that within USAF pilot IQ ranges, this variable would have any significance.

Thornton et al. (213) found a significant correlation between perceptual style (field dependence versus field independence, the ability to pull a figure from its background) and the ability to correctly identify targets in aerial photographs. Field independence also correlates positively with detection time of targets. Selection on the basis of degree of field independence may be a distinct possibility.

Powell (181) demonstrated that smoking first stimulates then depresses the ability of the eye to accommodate to changes in position of target stimuli. Johnston (115) found that smoker's visual search performance did not improve as much as non-smokers or smokers who abstained for two weeks. Selection on the basis of smokers versus non-smokers may result in significant improvement in search performance.

The possibility also exists of selection on the basis of individual differences that appear to be consistent across distinct groups of people. Burg (43) found that females demonstrate larger visual fields than men (Figure 24).

In summary, the following aircrew selection criteria may well relate to air-to-air target acquisition performance:

1. peripheral acuity,
2. perceptual style, favoring field independence,
3. nonsmoking, and
4. size of the peripheral field.

If large numbers of subjects are to be used in other simulated air-to-air studies, these measures would be simple to obtain and correlate with the air-to-air results.

Type of Instruction

Briefing

Bahrick et al. (8), in examining the effects of incentives upon detection of peripheral stimuli, found that conditions of high incentive facilitate performance on central tasks, but interfere with the performance of peripheral tasks.

In a study of the effects on visual search of the degree of generality of instructions given to photointerpreters, Enoch (70) found that less specific instructions led to more generalized search patterns. There is also a tendency to concentrate attention in the center of the display.

In the air-to-air situation, if one is unsure of where the conflicting air traffic may be, it may be advantageous to point out the need of searching the entire field (including edges and corners) to the observer.

In cases where the position of the conflict is known, the observer is greatly aided by more specific information.

PWI and Other Instrument Methods

Millhollon et al. (165) concluded that under good visual flight rule (VFR) conditions, if the pilot is given accurate information on the location of intruding aircraft, he has a high likelihood of detecting the target in time to take evasive action.

This information, supplied by Pilot Warning Instrument (PWI) systems, serves to reduce the uncertainty as to the target's location in a search situation.

Graham (88) conducted a very rigorous examination of PWI systems, examining aspects of the situation such as size of the aircraft, whether or not one or both pilots are able to see the position of the other aircraft, and approach angle. In all cases, PWI resulted in an increased probability of detection in conflict situations.

This result was also noted by Andrews (4). He also varied aircraft size and shape. See Figures 57 and 58 as an example of the data obtained.

Optical Aids

Sunglasses and Colored Filters

Katz et al. (121) found that neutral density filters (density = 0.65) led to a reduction in number of targets sighted in both structured and empty field search situation when compared to lenses designed to introduce farsightedness and to plano lenses (Figures 65 and 66). This reduction is largest for smaller targets, which may be critical in a visual air-to-air acquisition task where early detection is a must.

Hart (106) examined the effects of several colored lenses on visual target detection performance. He investigated yellow, red, and neutral colored filters as compared to a control condition of no filter, at a number of target ranges from 500 to 1450 m. There were no significant differences

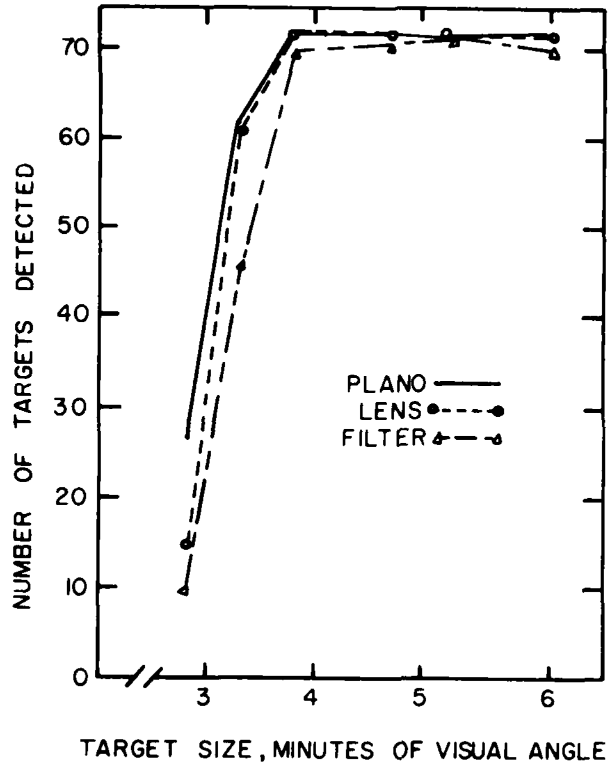

Figure 65. Number of detections in structured field as function of treatment (121, p. 14).

in number of correct detections or average response time. However, the observers preferred the yellow lenses almost two to one (see Table 21), which may lead to an improvement in detection in a real-world situation.

A paper by the NATO Advisory Group for Aerospace Research and Development (2) points to the crucial fact that selection of colored filters should not interfere with color discrimination (especially detection of red warning signals). This is a very strong argument for neutral density gray filters if they should be needed to be used to reduce discomfort from glare.

Scopes

Van Cott and Kinkade (215) have the following comments on the use of magnifying devices in target detection magnifying devices:

1. Lower the luminance of the target;

2. Lower the contrast between target and background;

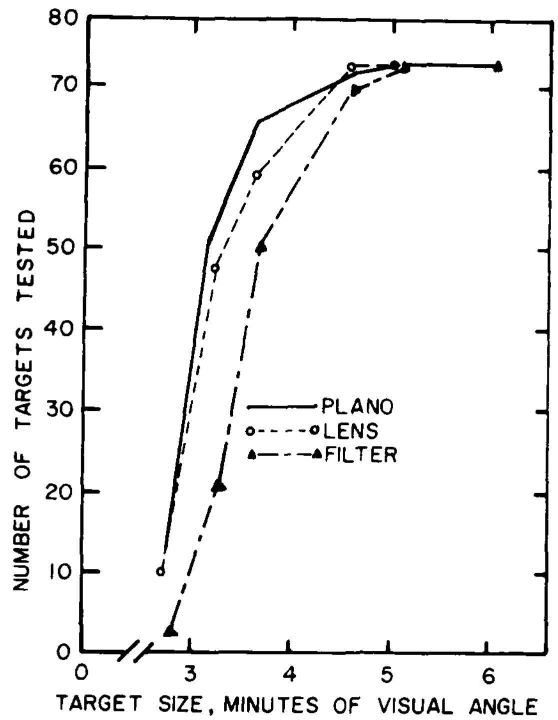

Figure 66. Number of detections in empty field as a function of treatment (121, p. 15).

3. Increase effects of vibration;

4. Decrease the size of the field of view; and

5. For use in aircraft, a hand-held or mounted binocular of 3 to 4 power should be used; higher powers severely restrict the field of view and increase the effects of vibration.

Binocular devices should be used to identify the target after it has been detected by other means, because of the restricted field of view and vibration effects. While some such stabilized systems (e.g., TISEO) have been proven successful, they are beyond the scope of this review and are not discussed for that reason.

Lenses and Far Vision

Whiteside (227) found that when a stimulus which can be sharply focused is present in the field of view, the involuntary focusing for near points in an empty field (myopia) is eliminated. The effectiveness of such a stimulus is a

TABLE 21. SUMMARY OF PERFORMANCE MEASURES FOR COLORED LENSES (106)

	YELLOW	RED	NEUTRAL	UNFILTERED	STAT. SIG.
Number of Correct Detections	35	32	32	28	N.S.
Number of Subjects Responding	21	21	21	17	N.S.
Range of Response Times in Seconds	0.1-58.2	0.8-57.7	1.3-43.5	0.1-58.8	N.S.
Average Response Time	17.38	15.02	12.65	15.05	N.S.
Number of False Positives	31	13	25	20	N.S.
Number of Times Preferred	13	7	2	2	$p<0.01$

function of its proximity to the line of sight. The most effective elimination of myopia occurs when the stimulus is in the line of vision. Beyond two degrees off the line of sight, it rapidly loses effectiveness, and at five degrees it loses almost all effectiveness in aiding the subject to focus at infinity. However, the closer the stimulus is to the line of vision, the more it may become an obstruction in the observer's foveal vision.

Whiteside (227) examined six collimated reticles and their ability to bring about accommodation for infinity. The reticles they investigated (in order of effectiveness, best to worst) are:

1. a hexagon of black spots,
2. a white cross,
3. a hexagon of white spots,
4. a white vertical bar,
5. a white horizontal bar, and
6. a simulated white cloud floor and horizon.

In another study, Brown (42) examined three other collimated reticles as compared to no reticle. He selected a circle of dots, a checkerboard pattern, and a gunsight pattern (Figure 67). He found that the use of a reticle at best gave only a doubling of acuity in empty-field conditions, but this was not a significant effect under aircraft search situations. He also noted that intersubject variability was greater than differences among reticles.

Matthews et al. (156) found that an aid in the form of a pattern with sharply defined edges placed at optical infinity resulted in a gain of 25-30% in performance (number of targets correctly identified and response latency) on a target acquisition task ($p < 0.005$). However, they found no significant differences among the three types of reticles they examined--a small central grid of lines, a larger grid, and a dot pattern. The latter two covered the entire field of view (Figure 68).

Katz et al. (121) examined the use of corrective lenses (-0.5 diopters) on target detection ability in homogeneous visual field situations. They found that performance with corrective lenses was insignificantly different from that with plano lenses (control) (Figures 65 and 66).

The use of corrective lenses may lead to difficulties in reading instruments and carrying out other tasks inside the

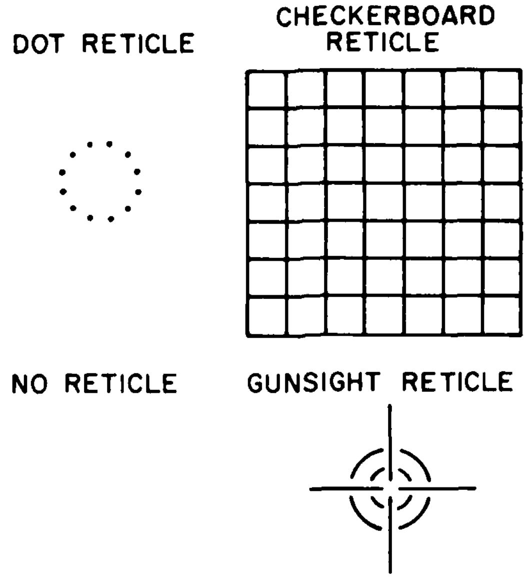

Figure 67. Reticle patterns used in study (42, p. 380).

cockpit. This problem may be alleviated by removing the glasses, but this is an operationally inappropriate solution.

Most recently, Post et al. (180) neatly put to rest much of the uncertainty concerning empty field myopia. They showed that lenses designed to accommodate the dark focus resting state to infinity resulted in the elimination of the empty field myopic performance. Thus, by measuring the dark focus accommodative level, and prescribing supplementary lenses to collimate that image, the subject is freed of the empty field myopia occasioned by a lack of visual stimulation. This result needs to be proven in a simulated air-to-air search environment, although the supporting basic research to date appears quite conclusive.

Helmet-Mounted Sights

Hughes et al. (112) examined the applicability of a helmet-mounted sight (HMS) in the context of a weapons delivery situation. They found that an operator equipped with an HMS can track static and moving targets efficiently and accurately.

There may exist the possibility of using the helmet-mounted sight as a form of head-up display, to present cueing signals to direct the operator's line of sight to a target which may be initially undetected or outside his field of view.

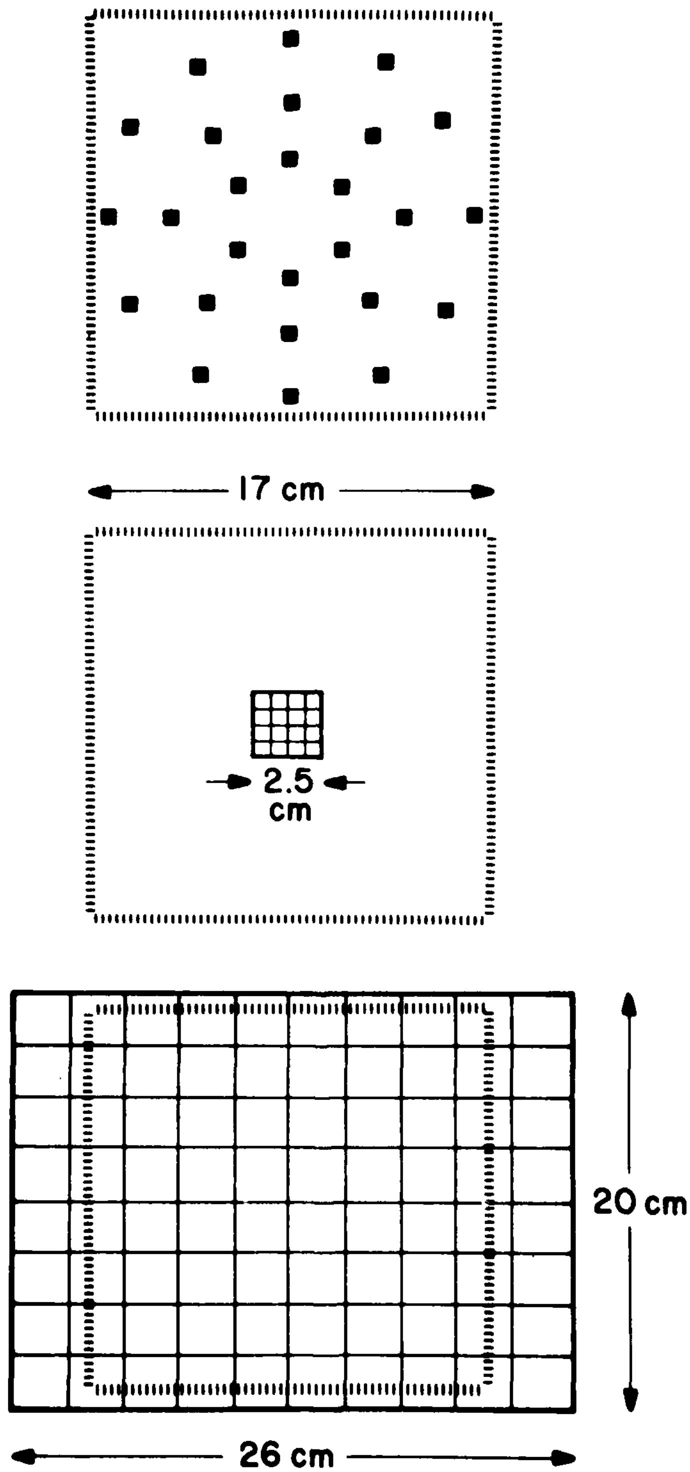

Figure 68. Configuration of accommodative aids (156, p. 736).

A major difficulty of an HMS may arise as a result of aircraft vibration or voluntary head movements which stimulate the vestibular system of the operator and produce reflex eye movements.

Another difficulty of HMS systems is the relatively long period of time required for fixation. The reason for this, according to Barnes and Sommerville (17), is that the operator must point his head at the target. This is essentially an unnatural motion, and is much slower than just moving the eyes to bring the target into foveal vision.

HMS systems have a definite use in attack situations for they may be used as aiming devices for weapons delivery systems. In this situation, the pilot has one hand on the stick, one on the throttle, and both feet on the rudder controls, tying up his hands with aircraft control functions.

HMS systems would not be useful as a direct means of target acquisition, as they involve slower movements (head movements) which would hinder rapid, efficient scanning of the visual field. However, they may reduce the empty-field myopia problem as they provide a constant, collimated image.

TV Image Enhancement

Abell and Philippou (1) examined the use of closed-circuit television (CCTV) as a method of enhancing the effective contrast of weak targets seen against the daylight sky. At low background levels, the human eye is not sensitive to background luminance, and is thus essentially target power limited. At high background luminance levels, the eye is contrast limited, especially as one moves away from the line of fixation.

If the luminance control on the television display is turned down so that the sky shown on the screen is dark, the luminance difference between the target and the sky is more easily seen. Then increasing the contrast control makes the spot depicting the target even brighter. This, in essence, cancels the sky luminance and enhances the effective contrast of the target with respect to the sky.

One difficulty with image enhancement is that it is contrast limited. The intervening atmosphere has the effect of degrading target-background contrast.

Another problem is that at low light levels, the performance of image intensifiers is limited by random fluctuations in the density of the arriving stream of photons (10).

They may also be seriously affected by aircraft vibrations, which may be magnified if any magnification is used in the display, or if the scanning device is not properly balanced.

Lights, Paint

Robinson et al. (188) examined pilots' ability to judge outcomes of simulated collisions and near-misses by varying the color scheme on the approaching aircraft. The approaching aircraft was treated with light and dark paint to identify major parts of the aircraft: top versus bottom, front versus back, left versus right. They compared these "coded" aircraft to an all white "uncoded" craft. The researchers concluded that visual coding of the type studied is not of significant help to a pilot in determining the existence of a collision threat.

Rowland and Silver (189) remark that in the absence of a technological breakthrough, efforts to increase conspicuity through exterior marking or painting will probably continue to be useless. They also recommended a white-on-top, black-on-bottom paint scheme, which leaves about one-fourth of a metal aircraft aluminum to cause specular reflection of sunshine. They recommend this scheme as giving the best contrast when viewed from above (white target on darker backgrounds) and below (black target on a white/blue brighter background).

When both aircraft are at the same altitude, the target is often of insufficient size to be detected, let alone identified on the basis of its paint scheme. In this situation, paint schemes are not a useful solution.

Connors (52) studied the conspicuity of target lights against a star background. For all colors examined, conspicuity was best at frequencies of 2-3 Hz. Connors also found that flashing lights are better than steady lights in terms of improved detection. As to color, in order of conspicuity, blue and green lights were responded to quickest, then white, yellow, and red, in that order.

RECOMMENDED RESEARCH PROGRAM

The above literature review has been used to develop recommended research activities which will provide both (1) a better understanding of the air-to-air target acquisition problem, and (2) techniques which can be implemented to yield improved air-to-air performance. In keeping with the objectives of this report, these following recommended research program elements are listed in priority order, highest priority first.

1. Search Technique and Training.

Very little research has been designed to investigate the effect of various search patterns on air-to-air (simulated or real) detection. It is necessary to determine the extent to which a uniform scan can be made and maintained by an observer looking at an unstructured field.

Various scan techniques could be determined from interviews, or perhaps experiments, with successful air-to-air combat pilots. Alternate scan patterns should be devised; groups of subjects should be trained in these scan patterns; and target detection performance should then be related to the groups' training types. Eye movement recordings would probably be desirable during training to provide feedback on the extent to which the subjects learn the specified patterns. Adaptive training shows promise in this application and should be evaluated further. Real-time recording and analysis of eye movements appear necessary to insure an effective search training program.

Present data do not lead us to any particular recommended scan pattern. Thus, logical patterns can also be generated, aside from those suggested by the pilot interviews. Possible patterns worthy of consideration include expanding spiral, "reading" (left-right, top-bottom), and horizontal with vertical dither.

The eye movement recording method to be used will require further study. NASA has successfully incorporated a Honeywell oculometer into a commercial airplane cockpit, and the U.S. Army at Ft. Rucker has successfully used a Mackworth-type head-mounted camera in helicopters. The remote camera, oculometer type seems most appropriate, although a combination of a head position sensing system and a helmet-mounted display with a recording device seems to offer promise also.

Much will depend on the constraints of the study. If done in a laboratory, the dual Purkinje image tracker can be used with real-time data processing and much higher accuracy.

2. Acuity and Air-to-Air Detection.

Existing data suggest that peripheral acuity may be strongly related to air-to-air target detection, and that foveal acuity might also be related. Further study is certainly required here, probably in a laboratory simulation, with large numbers of subjects. In addition to standard acuity measures, both foveal and peripheral, it is important to obtain contrast sensitivity functions (CSF) for all subjects. As Ginsburg (personal communication) has cogently pointed out, we need to understand the subject's functioning at all spatial frequencies, not just at the higher Snellen frequencies. CSFs should be obtained foveally and peripherally, and these should be related to simplified search and detection data. Eye movement recordings will provide additional information in these studies, in terms of search dynamics such as saccade extent and fixation duration.

The object of this research element would be to determine if visual selection variables can be used to screen for pilots who would have better air-to-air detection performance.

3. Workload and Air-to-Air Search.

We have very little information on the effects of crew workload upon air-to-air target detection. Pertinent questions include: Do pilots effectively time share in-cockpit duties with visual search? Under high workload conditions, is visual search less organized? Less effective? Is there more (or less) "looking without seeing" as workload increases?

These and other questions require careful study, in a simulation program of high fidelity and complexity.

4. Mathematical Model Improvement.

While the Akerman and Kinzly (3) model approach seems to be an improvement over previous research, additional development appears feasible and desirable. It is understood that some British data are perhaps pertinent; in addition, the new Navy air-to-air combat range should provide large amounts of controlled, parametric data. If quantitative conversion might be made from laboratory (simulation) results to field results, then additional simulation studies are suggested. Conversion of these data sources warrants additional consideration.

5. Empty-Field Myopia.

At the present time, it appears that empty-field myopia is a real operational problem at high altitudes and in a clear sky. While provision of lenses of dark focus correction power would apparently alleviate this problem, such correction might also interfere with other (in-cockpit) tasks. Thus, recent research has provided an understanding, but not necessarily a solution.

Other potential solutions include collimated reticles (e.g., on an HMD) and training to hold far-point accommodation. The HMD or HUD contribution to reducing empty-field myopia should be evaluated experimentally, either in flight or in a simulation experiment.

It is also suggested that training techniques be considered for the control of accommodation. Standard training techniques with accommodative measurement feedback should be evaluated. One might also consider more unusual training techniques, e.g., biofeedback. Once it is demonstrated that accommodation is trainable, then the transfer and retention of this skill to a simulated air-to-air complex search task must be evaluated.

Summary

It is extremely difficult to estimate the probability of success of a research program when it is designed to improve a long recognized operational shortcoming. Nevertheless, in the spirit of this literature analysis, and in conformance with the contractual statement of work, the following estimates of probability of success are given for each of the recommended research program elements.

1. Search Technique and Training: $p = 0.75$;

2. Acuity and Air-to-Air Detection: $p = 0.60$;

3. Workload and Air-to-Air Search: $p = 0.50$;

4. Mathematical Model Improvement: $p = 0.25$;

5. Empty-Field Myopia: $p = 0.25$.

ANNOTATED BIBLIOGRAPHY

Most annotations are those of the authors, taken verbatim. Some have been modified to delete totally irrelevant information.

1. Abell, G. R. and Philippou, G. Improved acquisition of targets seen against the daylight sky. Optical Engineering, 1974, 13, 105.

   Closed-circuit television equipment can aid an observer in visual acquisition of weak targets seen against a daylight sky. Theoretical and practical factors are reviewed, and results are shown.

2. Advisory Group for Aerospace Research and Development (AGARD), T. J. Tredici (Ed.), Visual aids and eye protection for the aviator. North Atlantic Treaty Organization, AGARD Conference Proceedings, No. 191, October 1976.

   This paper discusses the major ocular hazards encountered in military aviation and describes some protective measures which may be adopted. The hazards considered are solar glare, bird strike, wind blast, miniature detonating cord, lasers, and nuclear flash. The role of image intensities in aviation is also discussed.

3. Akerman, A. and Kinzly, R. E., Predicting aircraft detectability, Human Factors, 1979, 21, 277-291.

   A visual search model, VIDEM, has been formulated for predicting the detectability of a single unknown target in an unstructured surround. The intended application is aircraft detection. The model consists of four components: a liminal contrast threshold, a frequency-of-seeing curve, a soft-shell search representation, and discrete cumulation of single-glimpse detection probabilities. The formulation was developed by registering five existing models against three controlled search experiments. The five models used represent all appropriate laboratory data, including those of Blackwell, Lamar, Sloan, and Taylor. The search experiments included a large aircraft field test, with precise photometric target measurements correlated to the detection events. The model registrations were done using nonlinear parameter estimation techniques, and by comparing model

predictions to actual event cumulatives with the Kolmogorov-Smirnov statistic. The resultant VIDEM model is a derivative of Sloan's data, cast into the popular visual lobe equations of Lamar.

4. Andrews, J. W. Air-to-air visual acquisition performance with pilot warning instrument (PWI). Federal Aviation Administration Project Report FAA-RD-77-30, 1977.

Subject pilot tests conducted at the MIT Lincoln Laboratory have produced new data characterizing the ability of general aviation pilots to visually acquire potential collision hazards when aided by Pilot Warning Instruments (PWI). In this paper, major issues in the design of Pilot Warning Instruments are reviewed. Visual acquisition performance is described in terms of a non-homogeneous Poisson process and results of previous experiments are reinterpreted in this light. It is shown that the major test results can be explained in terms of an acquisition rate which is proportional to the solid angle subtended by the target. Model parameters appropriate for the Lincoln Laboratory flight test data are derived by maximum likelihood techniques. A statistical analysis of significance is performed for other factors which are not explicitly included in this model. Performance predictions for a wide variety of aircraft sizes, approach speeds, and visibility conditions are presented.

5. Attneave, F. Perception of place in a circular field. Amer. J. of Psych., 1955, 68, 69.

The ability of individuals to locate objects in visual space has engaged the interest of many investigators. Thus, there is a voluminous literature on depth perception, and recent studies have investigated the judgment of "azimuth," of "bearing," and of pointer-position on a linear scale. Such studies, however, have almost invariably dealt with a single spatial dimension at a time, and the extent to which their results are generalizable to two- and three-dimensional situations is not clear. It is evident from common observation, as well as from the unidimensional studies, that place-perception is largely dependent upon certain "anchors" or landmarks. One may reasonably suspect that as dimensionality is increased, these landmarks may acquire more important configurational properties than exist in simpler cases. In the present study, the observer was

required to reproduce, from immediate memory, the locations of points presented to him singularly on a circular screen in the frontal plane. The only landmark objectively present was the circular border of the field itself. The results derive their chief interest, however, from the fact that they imply the presence of certain additional landmarks of a subjective or implicit nature.

6. Avant, L. L. Vision in the Ganzfeld. Psychological Bulletin, 1965, 64, 246.

A summary of the evidence on exposure to structureless visual fields is presented. The data show the experience of such fields to be characterized by reports of: immersion in a "sea of light" which separates into figure and ground as brightness is increased, chromatic adaptation in colored fields, loss of efficiency in detecting the presence and movement of inhomogeneities introduced into the field, disorientation of the observer, an increased and fluctuating state of accommodation, and the occasional joint occurrence of an apparent cessation of function of the visual mechanism and increased alpha activity in the brain.

7. Backman, H. A. Visual accommodation variations during trans-Atlantic cockpit duties. Aviation, Space, and Environmental Medicine, 1976, 47, 438.

Twenty airline pilots measured their near point of accommodation employing a modified Prince's Rule. Measurements were performed periodically travelling east- and west-bound. Five clerical control subjects performed the same measurements over two consecutive days. The ranges of variability of the near point of accommodation were compared between the two groups, direction, and days. No statistically significant variability of accommodation was found in the comparisons.

8. Bahrick, H. P., Fitts, P. M., and Rankin, R. E. Effects of incentives upon reactions to peripheral stimuli. Journal of Experimental Psychology, 1952, 44, 400-406.

This experiment tested the hypothesis that an increase in incentive results in increased perceptual selectiveness favoring those parts of the stimulus field which are interpreted by subjects as most relevant to the expected reward. A modified Buxton pursuit apparatus was used as a continuous central-tracking task. Three kinds of intermittent peripheral stimuli, differing both in the amount of relevance to reward expectations and in the facility with which they could be detected in peripheral vision, were employed. Two incentive conditions were used. The low-incentive condition was produced by telling subjects that the trials were practice trials. The high-incentive condition was produced by offering a sliding-scale bonus which ranged from five cents to three dollars, for good performance. Results are in good agreement with the prediction that a condition of high incentive facilitates performance of a central task, but, in general, interferes with performance of peripheral tasks. The detrimental results of the bonus upon responses to peripheral stimuli were greatest on the peripheral task in which expectation of reward can be assumed to have been the least.

9. Bailey, H. H. Target acquisition through visual recognition: an early model. Office of Naval Research, Target Acquisition Symposium, Naval Training Center, Orlando, FL, 14-16 November 1972, pp. 113-122.

One of the early attempts to provide a quantitative model for predicting the capabilities of an observer in looking for pre-briefed targets is described. This model is structured according to three distinguishable psychophysical processes: Deliberate search over a fairly well-defined area; detection of contrasts (a subconscious retino-neural process); and recognition of shapes outlined by the contrast contours (a conscious decision based on comparison with memory). The probability that the three steps are completed successfully gives the probability of target detection. The foregoing is essentially a static model. Modifications to allow for the dynamics of flight approaching a target, and for individual target motion relative to the background, are also described.

10. Bailey, H. H. and Mundie, L. G. The effects of atmospheric scattering and absorption on the performance of optical sensors. RAND Corporation, Santa Monica, CA, Memorandum RM-5938-PR, March 1969.

This memorandum derives convenient analytical expressions for the effects of atmospheric scattering and absorption on the performance of optical sensors, including the human eye, photoelectric devices, pas-

sive infrared sensors, and active gated-viewing systems. Following S. O. Duntley and W. E. K. Middleton, the apparent or transmitted radiance, N, of a source is first shown (in the case of uniform illumination of the path and a spatially homogeneous spectrum of particle sizes and types) to be given by the expression $N = N_o T + N_g (1 - T)$, where N is the inherent (zero-range) radiance, T is the transmittance of the atmosphere, and N_g can be considered the radiance of the horizon sky measured at an appropriate azimuth. The factor that limits the performance of each sensor is then found in terms of the apparent radiance of the target and its surrounding background. Finally, the transmittance for this limiting factor is determined for each type of sensor with the aid of the above expression for the apparent radiance.

At background luminance levels exceeding about 10^{-1} cd/m^2 (corresponding to scene radiances prevailing until 15 min after sunset), the human eye's performance is determined by the contrast (Bt - Bb)/Bb between target and background, where Bt and Bb represent the brightness of the target and its background, respectively. The performance of photographic film is also usually limited by contrast. With the aid of the expression for radiance transmission given above, the contrast transmittance of the atmosphere is shown to be $t_c = (1 + K(1 - T)/T)^{-1}$, where K is the sky/ground radiance ratio.

At lower background luminance levels, the eye behaves as if it were photon-noise-limited, which is shown by the fact that the threshold value of (Bt - Bb)/Bb is essentially independent of the radiance level, as is characteristic of photon-noise-limited sensors such as image intensifiers and low-light-level TV equipment. The degradation due to atmospheric scattering of the performance of these devices and of vision at lower light levels is thus determined by t_{ph}, the atmospheric transmittance of this function, which is shown to be given by $t_{ph} = T^{1/2} \; 1 + K(1 - T)/T^{\;1/2}$.

When gated viewing is used, the effect of path luminance may be avoided by time separation, and the signal-to-noise ratio is directly proportional to the atmospheric transmittance T. Similarly, the S/N transmittance for infrared sensors is equal to TIR, the infrared atmospheric transmittance. In the case of targets against the horizon sky, the relevant transmittance is shown to be approximately equal to T for any optical sensor.

11. Baker, C. A. Visual aspects in collision avoidance of Air Force aircraft. Visual Search Techniques, Proceedings of a symposium, Publication 712, National Academy of Science, NRC Committee on Vision, April 1959.

The following statistics were made available by the Air Force Directorate of Flight Safety Research: (1) From January 1947 to June of 1958 the Air Force has experienced 634 mid-air collisions. (2) Collisions between military and civilian aircraft are rare; only 18 such accidents have occurred. (3) Approximately four out of every five mid-air collisions occur under visual contact conditions during daylight hours. (4) The majority of mid-air collisions occur within 20 miles of an airdrome. (5) Jet aircraft were involved over five times as frequently in major accidents as were non-jet aircraft. (6) The errors of commission or omission in mid-air collisions indicate that the pilots of jet aircraft perceive the other aircraft either not at all or too late to avoid contact.

12. Baker, C. A., Morris, D. F., and Steedman, W. C. Target recognition on complex displays. Human Factors, 1960, 2, 51.

This study was conducted to determine the speed and accuracy of form recognition : (1) the amount of distortion between the reference form and the target form, (2) the number of irrelevant forms in the display, and (3) the stimulus properties of the forms involved. The stimulus forms were generated by filling in, on a statistical basis, some of the cells of a 90,000-cell matrix. The subjects were shown a reference photograph of a target and instructed to locate that target on a display containing numerous other forms. Both criterion measures, viz., search time and errors, increased as a function of: (1) an increase in the number of irrelevant forms on the target displays, and (2) an increase in the difference between the resolution of the reference form and that of the target display. A quantitative description of the targets, which can be used to predict relative target difficulty, was developed.

13. Baker, C. A. and Steedman, W. C. Estimates of visually perceived closure rates. Human Factors, 1962, 4, 343.

The ability of subjects to estimate the relative distance travelled by a luminous object approaching on a

collision course and viewed in an otherwise stimulus-free field has been investigated. This research stems from an analysis of visual skills anticipated for certain manned space vehicle operations. The stimulus object at onset had an angular subtense of 4, 12, or 36 min of arc. It approached at two velocities from five starting distances, thus yielding a total of 30 experimental conditions. The subjects' task was to indicate when the stimulus object had traversed one-half of the original distance. Large constant and variable errors were evident in the estimates of subjects with no training at the task. Subjects provided with training, through knowledge of results after each estimate, demonstrated a considerable reduction in both constant and variable errors. After training, subjects were able to estimate when the object had reached the half-way point with an accuracy such that 50 percent of the half-way estimates fell within a range equal to 5 percent of the initial observation distance.

14. Baker, C. A. and Steedman, W. C. Man's visual capabilities in space: Perception of movement in depth. Unpublished manuscript, date unknown. Behavioral Science Lab, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

In a manned space flight, man will be required to perform certain visual tasks in the environment exterior to his space vehicle, such as inspection and rendezvous. Much is known about the visual cues man uses to evaluate closing rates, to extrapolate relative courses, and to estimate distances to other objects in his normal environment. Not much is known about man's ability to make such observations in space where the relatively unstructured visual environment will deprive him of many familiar cues. This paper describes research findings on man's ability to perceive relative movements of an object in depth as a function of luminance, angular size, and rate of relative movement when the object is viewed in an otherwise unstructured visual field. These data are useful in describing the capabiliites of man's visual system to perform terminal navigation for rendezvous in space. In general, they improve the basis for determining what functions are best assigned to man and what to machine in manned space vehicles.

15. Baldwin, R. D., Frederickson, E. W., Kubala, A. L., McCluskey, M. R., and Wright, A. D. Ground observer ability to detect and estimate the range of jet air-

craft flying over hilly terrain. HumRRO Division No. 5, Fort Bliss, TX, August 1968.

Sixteen observers were used in the tests. They received training in range estimation at Fort Bliss, Texas, just prior to the test. Observers were systematically rotated from target to target and were instructed to search a 180-degree sector for each trial, with early warning of an aircraft approach being provided in some trials. Observers were assigned a range to estimate for both inbound and outbound legs of the flights. Three real time events were recorded for each observer for each trial by means of an observer response box. These events were time to detection, time when the aircraft was at the estimated inbound range, and time when the aircraft was at the estimated outbound range. In addition to real time events, the observer completed a post-trial questionnaire for each trial. The questions pertained to whether or not smoke was seen at the time of detection, against what kind of background the aircraft was seen, and whether or not the aircraft was seen before it was heard. The average distance of the aircraft at detection for all trials was approximately 6,200 meters. A measure of aircraft apparent size (ASA) was found to be correlated with cumulative percent detection. Ground observers detected the aircraft before the pilot acquired the ground range target 60% of the time. The range estimation data indicated that observers can estimate the range of outbound aircraft more accurately.

16. Barmack, N. H. Dynamic visual acuity as an index of eye movement control. Vision Research, 1970, 10, 1377-1391.

The dynamic visual acuity, DVA, of man and monkey was determined and the associated horizontal eye movements were correlated with DVA. Monkeys have superior DVA, but inferior static visual acuity. The saccadic and smooth pursuit eye movements of monkeys are of shorter latency and higher velocity than those of man. Monkeys need only one saccade to attain a maximum smooth pursuit velocity of 140 deg/sec, whereas man needs two or more saccades to attain a smooth pursuit velocity of 90 deg/sec. It is probable that three factors determine DVA: (1) foveal visual acuity, (2) oculomotor control, (3) parafoveal visual acuity. It is shown that monkeys have better oculomotor control than man and it is inferred that monkeys have better parafoveal acuity. In addition, it is demonstrated that monkeys, like men, are capable of predictive eye tracking.

17. Barnes, G. R and Sommerville, G. P. Visual target acquisition and tracking performance using a helmet-mounted sight. Aviation, Space, and Environmental Medicine, 1978, 49, 565.

Experiments have been conducted on human subjects to assess the efficiency with which a helmet-mounted sighting system can be used to locate and track target sources in the horizontal plane. In the first experimental condition, in which the sight was aligned with discrete stationary target sources, the latency between target presentation and final target location was in the 2-4 sec range, dependent upon the amplitude of target offset and the rate of head movement. In the second condition, subjects were instructed to track a sinusoidally oscillating visual image with the sight. Tracking performance was found to be impaired when the frequency of oscillation was increased beyond 0.8-1.0 Hz. Recording of eye movement during both experimental conditions indicated that the impairment of performance could, in part, be attributed to involuntary eye movements consequent upon stimulation of the vestibulo-ocular reflex by the head-turning movements.

18. Barnes, M. J. Display size and target acquisition performance. China Lake, Naval Weapons Center Report No. NWC-TP-6006, 1978.

Two experiments were conducted to find factors that have an important effect on display size criteria in a cockpit-display system. Subjects in both experiments detected military targets simulating images from a TV camera looking obliquely forward as it is flown over the terrain. The results of the two experiments indicate that the physical size of a television monitor is not an important factor if MTF and visual angle are held constant. Of the factors studied, the four most important were: number of targets, visual angle of targets, target contrast, and target configuration. The data from the second experiment were used to generate a multiple regression model. The relationship between target visual angle and display size allowed the regression model to be used to predict performance as a function of display size.

19. Bate, A. J. and Self, H. C. Effects of simulated task loading on side-looking radar target recognition. Wright-Patterson AFB, OH: AMRL-TR-67-141, June 1968.

20. Becker, W. and Fuchs, A. F. Further properties of the human saccadic system: Eye movements and correction saccades with and without visual fixation points. Vision Research, 1969, 9, 1247-1258.

The execution of normal saccadic eye movements was found to depend upon clearly visible fixation points. Eye movements made in the dark or in an otherwise homogeneous field exhibited 10% longer durations and 16% slower maximum velocities than those between well illuminated targets. An increase in duration is already noticeable when the fixation points disappear 350 ms before the saccade. A second saccade often occurs despite the absence of fixation points. This phenomenon led to experiments which suggest that for large angles, the eye movement response is preprogrammed as two movements and that the second saccade in the package is determined by a position error sample of 70 ms.

21. Behar, I., Kimball, K. A., and Anderson, D. A. Dynamic visual acuity in fatigued pilots. US Army Aeromedical Research Laboratory, Report No. 76-24, 1976.

Six rotary wing aviators were subjects in a continuous operation regimen involving some 12 hours of flying and 3.5 hours sleep daily for five days. Estimates of performance on a dynamic visual acuity (DVA) task were obtained several times each day during the study using target velocities of 25 deg and 40 deg/s. DVA performance varied significantly during the fatigue regimen when measurements were made with target velocities of 40 deg/s; with lower velocity targets, differences in DVA scores were not signified. This indicates the need to tax the oculomotor system to demonstrate fatigue effects. Fatigue effects were partially obscured by practice effects which are considerable in the DVA task. DVA scores correlated only moderately with subjective estimates of fatigue intensity and flying performance, and IP ratings of performance, but the cluster of correlations provided a consistent picture.

22. Bendel, R. B. A visual dynamic detection model. Autonetics Operations Analysis Note 34, 31 July 1964.

The problem of visual detection from an aircraft flying at low altitudes is based upon a single glimpse probabilistic approach. That is, the eye gathers information while it is viewing or fixating on a region of space and the probability that the target is detected during this fixation is called the single glimpse probability. It should be emphasized that the single glimpse approach assumes that the identification of a target occurs during one fixation. Normally, the problem is separated into a "detection" problem and a "recognition" problem. At any rate, when we assume that successive glimpses are independent of each other, then this approach leads to an exponential distribution in the static problem--that is, when the distance between the target and the observer doesn't change with time. Now, in the dynamic problem, this approach leads to an integral which requires the average time to detect in the static problem as a function of range. This is accomplished by utilizing data which are obtained under various laboratory conditions.

23. Besco, R. O. The effects of cockpit vertical acceleration on a simple piloted tracking task. Human Factors, 1961, 3, 299.

This report presents the results of an experimental simulation study of the effects of vertical accelerations on the ability of pilots to track a simple, one-dimensional random signal on the "Pilot Operated Dynamic Flight Simulator." It was concluded that pilots could track significantly better with simple aircraft response motion cues. However, when gusts and turbulence were added to the cockpit motion, performance was significantly degraded.

24. Bhatia, B. and Verghese, C. A. Constancy of the visibility of a moving object viewed from different distances with the eyes fixed. Journal of the Optical Society of America, 1963, 53, 283.

It is observed that when the speed of a moving object, the length of a slit behind which the object appears at periodic intervals, and the duration of each exposure of the object at the slit are kept constant, the threshold of detection as measured by the linear size of the object does not vary with changes in the distance between the observer and the object over a range of 1 to 5 m. On the other hand, the threshold of detection as measured by the angular size of the object is markedly different for the distances of 1 to 5 m, when the angular velocity of the object, the angular size of the slit, and the duration of exposure of the object are kept constant for the two distances. The results are explained on the basis of a physiological correlate, at the psychovisual cortex, of the phenomenal size and speed of the object. This pattern is assumed to remain constant in spite of the changes produced at the retinal level by variations in distance between the observer and the moving object. The progressive decrease in the visibility of a moving object with increase in its linear velocity is not caused by the changes in the quality of discharge by individual retinal receptors, but is considered to be related to the stimulus pattern at the psychovisual cortex.

25. Blackwell, H. R. Contrast thresholds of the human eye. Journal of the Optical Society of America, 1946, 36, 624-643.

Experimental data are presented representing approximately 450,000 responses made by trained observers under laboratory conditions. Contrast thresholds are presented for stimuli brighter and darker than their background, and for two values of stimulus exposure. In each case, wide variations were studied in the parameters: stimulus contrast, stimulus area, and adaptation brightness.

26. Blackwell, H. R. The effect of target size and shape on visual detection: IV. Some relations with previous investigations. Report of Project MICHIGAN, University of Michigan, Willow Run Laboratories, February 1959, 2144-335-T.

Previous investigations were all concerned with the effects of target size and shape upon the visual detection threshold. The basic approach of the present report is to reanalyze data from the earlier reports in the series to facilitate comparison with the data of earlier investigators. It is shown that the data of Brown and Niven, and Niven and Brown, are in good agreement with the data from the first paper in the present series by Kristofferson and Blackwell. The data of Fry are also shown to be in general agreement with the much more extensive data of Kristofferson and Blackwell. The data of Lamar, Hecht, Shlaer, and Hendley and those of Lamar, Hecht, Hendley, and Schlaer, are shown to agree with Kristofferson and Blackwell data except for large targets of extreme shape. An explanative hypothesis is offered to account for the difference in terms of an artifact which could have been involved in the search procedure used by Lamar et al. Previously unpublished data are offered to support this hypothesis. An investigation has been made of the adequacy of the

perimeter theory of Lamar et al. in rectifying data from the previous papers in this series. This formulation is shown to have considerable predictive success with the data of Kristofferson and Blackwell. However, it is believed that the formulation cannot be supported in detail, and that the empirical and theoretical formulations offered in earlier papers in the present series represent refinements on the perimeter theory.

27. Blackwell, H. R. Neural theories of simple visual discriminations. Journal of the Optical Society of America, 1963, 53, 129-160.

Simple visual discriminations such as detection of presence and recognition of small differences in the spatial and temporal patterns of objects have been explained in some detail in recent years by variants of the physical quantum theories. The present paper summarizes the status of an alternative group of theories, which are classed as neural, primarily to distinguish them from the physical quantum theory, and compares the two groups of theories. The neural theories are models of the visual system as a whole and include assumptions concerning the transformation of stimulus to sensory events, and the decision process involved in discrimination. They are neural by inference only, and rarely specify the type of neural activity or the neural site at which the events occur. The bulk of the paper is devoted to a description of specific neural theories, attributable to the writer, concerned with (a) the detection process and the form of threshold probability data; and (b) the relation of threshold delta I/I to I, and to the spatial and temporal characteristics of the stimulus. These theories are compared to selected related theories. The Swets-Tanner decision theory is contrasted with the present detection threshold theory and various lines of evidence are summarized. It is shown that data previously used to support the Swets-Tanner theory are inconclusive. Brief evidence against the Swets-Tanner theory comes from data obtained in a stimulus-comparison experiment, and from the contradiction implied when the relations assumed to exist between stimulus and sensor magnitudes over the threshold range are extended to a wider range. Evidence is presented which is in favor of the present theories and opposed to the neural theories of Graham and his colleagues which related threshold delta I/I to the spatial and temporal characteristics of the stimulus. This evidence comes primarily from detection thresholds for stimuli composed of twin spatial points or double temporal pulses, which the Graham theories cannot explain. In addition to spatial and temporal summation, double spatial and temporal stimuli exhibit probability summation whenever the sensory correlates of the stimuli exhibit twin modes. A 5-6 cps scanning mechanism is shown to exist which breaks up prolonged temporal stimuli and provides probability summation along the separate parts.

28. Blackwell, H. R. and Bixel, G. A. The visibility of non-uniform target-background complexes: I. Preliminary experiments. Rome Air Development Center, Griffiss AFB, NY. Technical Report No. 890-1, 1974.

A study has been made of the extent to which it is meaningful to assign a value of "effective contrast" to represent the visibility of a target in a target-background complex in which target and background may be of non-uniform luminance. The meaningful assignment of a value of effective contrast implies that this value constitutes an index of the visibility of the target in a target-background complex which possesses some degree of invariance or generalizability. The present study has tested the extent to which a value of relative contrast assigned to a target-background complex on an arbitrary basis appears generalizable to various values of general luminance and to various values of detection probability.

Experiments were first conducted in which the threshold value of relative contrast was established at various luminance levels, utilizing a method of adjustment to threshold. Experiments were also conducted in which the probability of detection was established as a function of values of relative contrast, utilizing a method of constant stimuli with a temporal forced-choice discriminatory criterion. The relations of the threshold value of physical contrast to background luminance, and the relations of detection probability to physical contrast were also established with target-background displays in which each was of uniform luminance. It was found that a conversion factor could be found in each series of experiments which would adjust values of relative contrast for non-uniform backgrounds to values of physical contrast for uniform backgrounds. This implies that a value of effective contrast assigned at one level of luminance or probability may be generalized to other luminances or other probabilities.

29. Blackwell, H. R. and Moldauer, A. B. Detection thresholds for point sources in the near periphery. Bureau of Ships, Department of the Navy, Contract No. NOBS-72038, Washington, D. C., June 1958, AD-759 739.

Two observers have obtained visual detection thresholds for the foveal center and for 32 locations in the peripheral retina within a radius of 12 deg from the fovea. The locations have fallen eight equally spaced meridians of the visual field, at distances of 1, 2, 4, 8, and 12 deg from the fixational center. These measurements have been made at each of nine levels of background luminance, ranging from 0 to 75 ft-Lamberts. A total of 368,250 observations have been made, using the temporal forced-choice variant of the method of constant stimuli. The target was a circle, whose diameter subtended 1 minute of arc; the exposure duration was 0.01 s.

30. Bloomfield, J. R. Visual search. Ph.D. dissertation, University of Nottingham, October 1970.

For most of the experimental work reported here a competition task was used, with the target having to be located when other confusing, non-target stimuli were also present in the display. A model of search, derived from basic search theory, was found to handle some of the data for the competition situation, and data by others for search in a plain background. The model gave equations suggesting that search time is a function of fixation time, total search area, and the area within which the target can be seen in a single fixation. The latter term could be related to measurable characteristics of the target and background stimuli. Finally, the view is put forward that observers search in a methodical way, and that the degree of efficiency with which they do this depends on the amount of overlap between successive fixations. The earlier search equations for exhaustive efficient search are amended, though those based on an independent fixation strategy have to be abandoned. A cumulative probability of detection equation accounting for response time factors, fixation overlap, and the characteristics of targets and no targets is given.

31. Bloomfield, J. R. Experiments in visual search. Visual Search, Symposium conducted at the spring meeting, 1970, Committee on Vision, Division of Behavioral Sciences, National Research Council, National Academy of Sciences, Washington, D. C., 1973.

The work described here was carried out in an attempt to elucidate some of the problems involved in visual search. There were two general objectives: (1) to provide a sound body of empirical data, and (2) to develop a viable theoretical framework. Several experiments have been performed with competition search tasks in which the target had to be located when other nontarget stimuli were also present in the display. An adaptable apparatus was devised. This enabled a series of studies to be undertaken, some of which are reported here. It was found that as the difference in size of targets and nontargets decreased, search times increased for both regularly arranged and irregularly arranged stimulus displays. For some easier targets, the location times were largely dependent on response factors, while the times became more and more dependent on search factors as the target-nontarget difference decreased. A comparison of two display densities led to the suggestion that search time is a function of the square root of the number and density of nontargets. Search times appear to be distributed exponentially. Howarth and Bloomfield (1963, 1969) derived a model of search that makes use of the linear relationship between threshold stimulus size and retinal eccentricity. Using this model, it is possible to relate mean search times to target-background characteristics, in particular to the square of the difference in diameter of target and nontarget discs. This approach is illustrated here. It is argued that the fastest search time obtained for a given target can be taken as an estimate of response time. This time is not related to the square of the diameter difference but to the difference itself. It is suggested that these two relations, of mean search time and fastest search time with target-background characteristics, might be used to develop a measure in terms of diameter differences for search situations in which the target and background differ in other ways than size. This is illustrated for grouped targets and targets differing in shape. While some progress has been made, we remain a long way from being able to deal with many complex search situations.

(Howarth, C. I. and Bloomfield, J. R. Towards a theory of visual search. AGARD Conference Proceedings, No. 41, A.2, 1968.) (Howarth, C. I. and Bloomfield, J. R. A rational equation for predicting search times in simple inspection tasks. Psychonomic Sci., 1969, 17, 225-226.)

32. Bloomfield, J. R. Theoretical approaches to visual search. *Human reliability in quality control*, ed. by J. G. Fox and C. G. Drury. London: Taylor and Francis, 1975.

After a discussion of peripheral visual acuity and its relationship to visual search, various theoretical approaches to visual search are reviewed. Some of these have very limited value, others have more obvious uses. Descriptive equations have been developed from and used in studies of visual search. These make use of the relationship between search and acuity. Possible applications to visual inspection of the ideas developed by search theorists are discussed.

33. Bloomfield, J. R. The development of training procedures for air-to-air search. Unsolicited proposal.

A two-phase, twelve-month program of research is proposed. The objective of the program is to devise and develop training procedures for air-to-air target acquisition. Efficient training methods and techniques are needed in order that observers, faced with the complex and demanding task of air-to-air target acquisition, might achieve the highest performance levels they are capable of as quickly as possible. The first phase of the program is analytical. It consists of two tasks. First, air-to-air target acquisition will be analyzed and evaluated. Available documentation will be reviewed, air-to-air simulation facilities will be visited, and discussions will be held with experienced pilots. In the second task, training methods and procedures will be devised and the most promising of them will be selected. A brief technical memorandum will be issued at the end of the first phase. The second phase is experimental, and it consists of four tasks. First, preparations will be made so that the selected training techniques and a test task can be administered. The second task will be to conduct the experiment. The test task will be presented to all the observers before and after they receive a different type of training. Thirdly, the data obtained before and after training will be analyzed to determine which training techniques are most effective. Finally, details of the research will be given in a report that will be the final product of the program.

34. Bloomfield, J. R. and Howarth, C. I. Testing visual search theory. NATO Advisory Group on Human Factors Symposium, Image Evaluation, Munich, August 1969.

In our previous work, we have suggested two relatively simple equations to handle search data for targets of varying size in competition and plain background search situations. One equation gives mean search time as a function of fixation time, total search area, and the area within which the target can be seen in a single fixation. In the second equation, the last term has been replaced by a function that is related to measurable characteristics of the target background relationship. The research reported here describes how we have separately determined each of the terms in these equations for the competition search situation. We have amended the second equation, to some extent, as a result of these experiments. In addition, we have found that, when compared with the actual mean search time obtained for the most difficult of the targets, our theoretical predictions were surprisingly good. They are poor for the smaller targets. Our equations have some predictive value, but they do not account for all the data. However, we hope to be able to extend our approach so it is more satisfactory, by attempting to deal directly with cumulative search time distributions and by incorporating, in some way, a measure representing response time in our measures.

35. Bloomfield, J. R., Marmurek, H. H., and Traub, B. G. Color and texture differences in embedded target visual search situations. Proceedings of the Human Factors Society, 18th Annual Meeting, 1974.

This study provides a direct investigation of embedded target visual search situations. The relationships between measures of visual search performance, peripheral visual acuity, and ratings of discriminability were determined. The embedded target displays were constructed using a color and a monochrome texture background. They were used in a rating study, in which the production magnitude rating method was used, and in visual search and peripheral acuity experiments. In the first of these, 23 observers rated the discriminability of five color targets from the color background, and of four black and white targets from the monochrome background. There were two visual search experiments. Five observers searched the color background for the color targets, and six searched the monochrome background for the black and white targets. In both experiments, after practice, there were 60 search trials per observer per target. The extent into the periphery that the five color targets could be seen when the color display was exposed for 0.3 s, was measured for the five observers used in the color search task. The same measurement was made with the black and white stimulus materials for four of the six observers used with the monochrome task. For the color stimulus materials, a set of simple relationships was found to describe the measures obtained in all three experimental areas. The results with the monochrome texture material did not fit the same equations so well. The equations were based on those developed by Howarth and Bloomfield for search situations involving targets that were confused with other nontarget objects. For the color display, the relationships among mean search time (t), peripheral visual acuity (A), and rated discriminability (D), could be summarized as follows: This is an encouraging finding. It leads one to hope that predictive procedures developed from these simple relationships can be applied to a wide range of complex search situations.

36. Bloomfield, J. R. and Modrick, J. A. Cognitive processes in visual search. Proceedings of the Sixth Annual Congress of the International Ergonomics Association, 1976.

This approach to visual search introduces the concepts of organization, variable field of view, and congratulation. It builds upon ideas developed in glimpse/detection lobe models of visual search. It suggests experiments that go beyond an assessment of variables that affect visual search performance, in the hope that these will eventually lead to a comprehensive cognitive theory of visual search.

37. Boynton, R. M. and Bush, W. R. Laboratory studies pertaining to visual air reconnaissance. Wright-Patterson AFB, OH, WADC Technical Report 55-304, April 1957.

This is the second part of a three-stage program concerning the investigation of relevant variables involved in visual air reconnaissance. Using the apparatus and procedures developed during the first stage, experimentation has been conducted to determine the effects of (a) brightness contrast, (b) an extended range of distances, (c) response tendencies of the subjects, (d) number of figures in an array, (e) exposure time, and (f) experience with an array on the ability of human subjects to detect and correctly identify a rectilinear form among a group of curvilinear forms. Results are presented as percent correct recognition (i.e., correctly identifying a "target"), although some data for detection and error responses are also given. Recognition is found to increase with (a) increased contrast, (b) decreased distance, (c) decreased numbers of figures, and (d) increased exposure time, but does not significantly change with either (a) response techniques, or (b) experience with arrays. Both detection and errors are affected by response tendencies. Conclusions from this research and some considerations of further experimentation are presented in the text.

38. Boynton, R. M., Elworth, C., and Palmer, R. M. Laboratory studies pertaining to visual air reconnaissance. WADC Technical Report 55-304, April 1958.

This is the third and final part of a three-stage report on a program concerning the investigation of relevant variables involved in visual air reconnaissance. A mathematical relationship is worked out which yields the contrast required for 60% correct recognition as a function of subject-target distance, exposure time, and number of confusion forms (struniforms) among which the critical target may be located. By translating altitude into experimental distance, aircraft velocity into viewing time, and conditions of viewing (including meteorological conditions) into contrast, predictions are made about how performance should vary as a function of altitude, from 500 to 30,000 ft. General statements are given which attempt to summarize the results of these calculations. Further studies are reported in which a preliminary attempt is made to understand individual differences in searching ability as the related parafoveal form recognition, visual acuity, and eye movements.

39. Bradford, W. H. A mathematical model for determining the probability of visual acquisition of ground targets by observers in low-level high-speed aircraft. Sandia Laboratories, Albuquerque, NM, SLA-74-0141, April 1974.

A cumulative distribution function for determining the probability of visually acquiring ground targets by observers in low-level high-speed aircraft has been formulated as a function of range from target and a number of other parameters believed to have a major influence on target acquisition. Some illustrative calculations are included.

40. Brenton, J. G. The mathematical model and computer program description for Test 4.4, visual reconnaissance. Sandia Corporation, Albuquerque, NM, DC-TN-2047-4, Contract No. 7402, 13 January 1967.

A performance measure for the visual acquisition of targets by pilots engaged in reconnaissance is developed. Area, point-to-point, and route reconnaissance are considered. A flow diagram of a digital simulation of the model is presented with some sample calculations.

41. Brody, H. R., Corbin, H. H., and Volkmann, J. Stimulus relations and methods of visual search. Visual Search Techniques, Proceedings of a Symposium, Publication 712, National Academy of Sciences, Committee on Vision, April 1959.

The task is to describe briefly two experimental situations and to state the principal results. One situation deals with horizon search, and the other with search in a rectangular matrix. The main stimulus relations that our experiments have turned up: first, the search time varies directly as the angular range over which the subject must search. This relation appears to be linear. Secondly, search time varies inversely with the brightness of the stimuli, though we did not determine the precise form of the relation. These experiments imposed no special method of search upon the subject. Next is a special dependent variable: the angular range within which detection is rapid. This range varies with target brightness. The results show that at high brightness levels the brief stimuli could be seen anywhere within 160°%. At the middle brightness the effective range was decreased to about 70°%, and at the low brightness to only 15°%. Under different experimental conditions, when both eye and head movements were permitted, some brief stimuli were not seen even at high brightness. (Angular range shrank to 90°%.) Searching behavior produces misses as well as discoveries. In a paced search situation, fast rates are better than slow ones, but there is an optimal rate of search of about 5 s per cycle in this experiment.

42. Brown, R. H. Empty-field myopia and visibility of distant objects at high altitudes. American Journal of Psychology, 1957, 70, 376.

Pilots and observers in planes at altitudes of 35,000 ft or higher frequently report difficulties in the visual detection of other aircraft. Among the factors listed as being contributory to these difficulties are anoxia, glare, windscreen obscuration, low-contrast and small apparent size of other planes at desirable ranges of detection, the narrow field of vision for objects near the threshold of detectability, difficulty of systematically scanning the sky, and nearsightedness induced by an empty field. The purpose of the present study is to determine the extent to which a collimated reticle corrects for empty-field nearsightedness and aids in visual detection.

43. Burg, A. Lateral visual field as related to age and sex. J. of Applied Psychology, 1968, 52, 10.

Lateral nasal and temporal visual field measurements were obtained by means of a screening perimeter for nearly 17300 Ss, ages 16-92. The major findings are: (a) temporal and total fields are maximum to about age 35, after which field constricts progressively with advancing age, (b) nasal fields increase to a maximum occurring about age 35 or 40, after which a progressive decline takes place, and (c) females consistently demonstrate slightly larger visual fields than men. Possible interpretations for these and other findings are presented, and additional research is suggested to explain some of the relationships obtained in the study.

44. Burg, A. and Hulbert, S. Dynamic visual acuity as related to age, sex, and static acuity. J. of Applied Psychology, 1961, 45, 111.

The results of this research clearly indicate that a person's ability to discriminate a moving target cannot be accurately predicted from his static acuity, and that the adequacy of this prediction decreases as the speed of the moving target increases. The exact nature of these factors, other than static acuity that influences dynamic acuity, is not yet known, but it is probable that they involve the efficiency of the entire oculo-motor system. No relationship was found between dynamic visual acuity (DVA) and either critical flicker frequency or lateral phoria (ACA ratio). Also, the number of subjects (small) in the higher age brackets makes impossible a generalization as to the effects of age on DVA performance. Finally, the results suggest a consistent and significant difference in performance between male and female subjects, the latter performing less adequately. It is suggested that testing of a large number of additional subjects of both sexes and of all ages will serve to correct the several inconsistencies appearing in these results, but it is not expected that the basic conclusions will be significantly altered. Once having established DVA as a relatively independent, reliable measure of visual ability, the next step becomes the study of the relationship between DVA and performance in a variety of tasks where discrimination of moving objects plays a key role, such as in driving, ball playing, and the like. Studies are currently underway toward this end.

45. Camp, R. W. Military characteristics for time-sharing scan trainer. NAVTRAEQUPCEN Task No. 8681 52-73, January 1974.

The time-sharing concept refers to the alternation of attention between inside-the-cockpit and outside-the-cockpit information. With emphasis on aircraft performance and instrument flying, only a small amount of time is spent looking outside the cockpit in modern naval aircraft. Since pilot's total available outside-cockpit scanning time is small, prevention of mid-air collisions requires that pilots have skills in sharing their scan attention.

46. Chapanis, A. and McCleary, R. A. Interposition as a cue for the perception of relative distance. Journal of General Psychology, 1953, 48, 113-132.

Psychologists appear unanimously agreed that interposition, superposition, or interception, as it is variously called, is an important monocular cue for the perception of relative distance. In discussing this phenomenon, many writers, in fact, dismiss it with a brief definition and short statement to the effect that interposition is an obvious cue of relative distance. This perfunctory treatment may be due in part to long familiarity, for the origins of this principle are lost in antiquity; even primitive man made use of the technique in his drawings. For all our certainty, however, the precise mechanism of interposition is still to be determined.

47. Chisum, G. T. Prediction of airborne target detection. Naval Air Development Center, Warminster, PA, 3 June 1977.

The visibility of a uniformly luminous object depends on the apparent contrast between the object and its background, the angular subtense of the object, the contrast threshold of the observer at the level of luminance to which the eyes are adapted, the conditions and techniques of observing, and the shape of the object. Techniques for combining the influence of the various factors have been applied to the problem of predicting airborne target detectability. Recommendations for achieving the desired detectability are made.

48. Chisum, G. T. and Morway, P. E. Laboratory assessment of the AN/PVS-5 night vision goggle. Aviation, Space and Environmental Medicine, 1975, 46, 1390.

Laboratory assessment of the AN/PVS-5 Night Vision Goggle was conducted. Visual fields, goggle infrared source, usable range, and detectability of targets with the goggles were measured. Illumination levels of -8.37 and -9.17 log lm/cm^2 were adequate for 90% detection of 0.14 and 0.07 acuity targets, respectively. Calculations of distances at which various surface and airborne targets subtended comparable visual angles and tables of natural brightness conditions are presented to permit the translation of laboratory values into field conditions. While further field evaluation is anticipated, the laboratory assessment indicates that the goggle can significantly facilitate aircrew night visual performance.

49. Clark, B. Visual space perception as influenced by unusual vestibular stimulation. Visual capabilities in the space environment, ed. by C. A. Baker. New York: Pergamon Press, 1965, p. 91.

During flight in aircraft and spacecraft, pilots are regularly subjected to unusual force environments. These forces not only influence a wide variety of pressure-sensitive mechanisms but, in particular, they stimulate the vestibular mechanism of the inner ear. The latter source of information regarding spatial orientation may be in accord with information from direct visual stimulation or it may be in conflict with it. In the first case, veridical space perception may be expected, while in the second the perception is frequently nonveridical. This results in constant errors in judgment with respect to motion of visual objects and in the pilot's estimates of the object's position. These errors, referred to by pilots as "vertigo," are believed to be of importance in piloting aircraft and spacecraft where the pilot's task involves actions based on visual space perception.

50. Cohen, W. Apparent movement of simple figures in the Ganzfeld. Perceptual and Motor Skills, 1958, 8, 32.

If autokinetic movement under conditions of darkness results from an inadequate visual framework, then similar movement of a figure in an illuminated uniform visual field should occur. The apparatus used to investigate this hypothesis has been described in detail (Cohen, 1957). O, using his right eye alone, looked into an illuminated sphere and was presented with a uniform field containing an 8 cm circular figure at a distance of 1 m. Intensity and chromaticity of the figure were independently varied by changing the illumination of an adjoining sphere. Fifteen graduate students observed a series of situations in which differences between figure and field were systematically varied. O described each situation during 3-min periods of stimulation, followed by 2-min rest periods. Each experimental session lasted 90 min. Spontaneous autokinetic movement of the figure was reported by 11 Os in about 40% of the situations in each series. There was a predominance of movement to the right which may have resulted from the use of the right eye alone. The frequency of reports of movement was not dependent upon the kind of difference between figure and field, i.e., chromatic differences or intensity differences. An amoeba-like movement of the figure was often produced by chromatic differences alone. Forward movement and pulsation was sometimes produced by large intensity differences. The occasional disappearance of the figure was always preceded by its movement. When the intensity of the figure was gradually changed, about 70% of the time all Os reported movement of the figure and the fog-like field in opposite directions. Thus, with increasing intensity differences, the figure moved forward and the fog receded, while with decreasing intensity differences, the figure receded and the fog moved forward. Under these conditions, movement was sometimes experienced without any change in apparent distance. However, even when a change in apparent distance was reported, there was no systematic change in apparent size. (Cohen, W. Spatial and textual characteristics of the Ganzfeld. Amer. J. Psychol., 1957, 70, 403.) (Note by compiler: The above is the entire paper.)

51. Cohen, W. Form recognition, spatial orientation, perception of movement in the uniform visual field. Visual Search Techniques, Proceedings of a Symposium, Publication 712, National Academy of Sciences, NRC Committee on Vision, April 1959.

Stimulus gradients of intensity, chromaticity, as well as texture, are distributed in most cases throughout the visual field. There are, however, situations in which such gradients are absent, and the distribution of stimulation in the visual field is relatively uniform. Since relatively brief exposures to the uniform field are far less detrimental to perceptual accuracy than prolonged exposure to the field, some device which permitted periodic differentiation of the field might prove to be useful. Another possibility would be to train the observer to blink frequently and look away from the field whenever possible.

52. Connors, M. M. Conspicuity of target lights: the influence of color. NASA Technical Note, NASA TN D-7960, November 1975.

This study investigated the conspicuity, or attention-getting qualities, of foveally-equated, colored lights, when seen against a star background. Subjects who were periodically engaged in a distracting cockpit task were required to search a large visual field and report the appearance of a target light as quickly as possible. Targets were red, yellow, white, green, and blue, and appeared as either steady or flashing lights. Results indicate that red targets were missed more frequently and responded to more slowly than lights of other hues. Yellow targets were acquired more slowly than white, green, or blue targets; responses to white targets were significantly slower than responses to green or blue targets. In general, flashing lights were superior to steady lights, but this was not found for all hues. For red, the 2 Hz flash was superior to all other flash rates and to the steady light, but none of which differed significantly from each other. Over all hues, conspicuity was found to peak at 2-3 Hz. Response time was found to be fastest, generally, for targets appearing between 3 deg and 8 deg from the center of the visual field. However, this pattern was not repeated for every hue. Conspicuity response times suggest a complex relationship between hue and position in the visual field that is explained only partially by retinal sensitivity.

53. Cowan, T. M. An observing response analysis of visual search. Psychological Review, 1968, 75, 265.

An assumption is made that the perceptual processes involved in scanning or search are similar to those postulated in observing response (OR) models of discrimination learning. A model of visual search is proposed which treats scanning behavior as a sequence of discrete ORs. The basic model is stochastic, and the sequence of ORs is represented by an absorbing Markov chain where the absorbing state is target location. It is shown that the model is capable of describing search times for (a) displays of varying densities, (b) search displays with multiple cues in a non-target (irrelevant) dimension, and (c) search tasks with compounded cues.

54. Davies, D. R. and Tune, G. S. Human vigilance performance. New York: American Elsevier Publishing Co., 1969.

55. Davies, E. B. Theoretical television detection ranges. Royal Aircraft Establishment Technical Note WE-64, June 1964.

This paper considers the properties of a television chain in terms of what the eye can detect on the television display. The television chain is considered to have a simple transfer function for contrast which is related to the size of the image of the object on the display, and the theory considers the amount of contrast which the eye requires to see this object; no account is taken of the fact that this object has a blurred outline. The effect of electronic noise is taken into account to the extent that it increases the contrast requirements of the eye. Some graphs are presented which indicate the implications of various television parameters on the ranges at which detection of sample objects is possible.

56. Davies, E. B. Visual theory in target acquisition. Royal Aircraft Establishment Technical Memorandum WE-1301, March 1969, presented to the AGARD-ASMP, London, October 1968.

The theoretical approach to visual search for a target based on the target's contrast and size and the concept of visual lobes is reviewed briefly. New flight data for foveal contrast/size thresholds related to the maximum detection ranges of prominent ter-

rain objects are found to compare favorably with laboratory test data from much simpler visual tasks. Two laboratory search experiments analyzed in terms of visual theory are shown to agree well with it, with little modification of the data used in the theory from certain selected but otherwise standard data. In particular, glimpse times of the order 1/3 to 2/3 s are found to be quite adequate to describe the experimental results.

57. Davies, E. B. A comparison of visual search theory and R.R.E. experimental data. Royal Aircraft Establishment Technical Report 69057, March 1969.

A visual search experiment undertaken at the Royal Radar Establishment, Malvern, has been analyzed in terms of visual search theory based on "visual lobes" and "random glimpses." The search situation investigated had provided a particularly interesting check on theory as it increased with time, under carefully controlled conditions. Close agreement has been established between the experimental results and theory, using degraded contrast thresholds from Blackwell's 8-position search in 6 s experiment together with J. H. Taylor's data for the extra contrast required for off-axis vision, and fixations of 2/3 s. The degradation required on the foveal contrast threshold appears to vary slightly with target size in that small targets require larger degradation than large targets. Theoretical predictions based on the "visual lobe" equation give optimistic results and show little effect of target size. Some interesting facets of the application of theory to these experimental circumstances are also presented.

58. Davis, D. R. Human errors and transport accidents. Ergonomics, 1958, 2, 24.

The paper discusses the part played by three psychological processes, here called "the false hypothesis," "pre-occupation," and "emergency mechanisms," in the causation of transport accidents. Some of the experiments in which these processes have been studied in the laboratory are described. Explanations of the errors responsible for certain train collisions, when the driver had passed one or more signals at danger, and for certain aircraft accidents are suggested by reference to one or the other of these processes.

59. Deutschman, J. N., Hammill, H. B., and Sugarman, R. C. Visual contrast reduction investigation. Buffalo, NY: Cornell Aeronautical Laboratory, AFAL-TR-70-11, February 1970.

60. Didday, R. L. and Arbib, M. A. Eye movements and visual perception: a "two visual system" model. International J. of Man-Machine Studies, 1975, 7, 547.

Eye movement is one of the few externally measurable activities of visual perception, and provides a checkpoint for models of perceptual processes. Here the model of Arbib and Didday (1971) is compared with that of Noton and Stark (1970, 1971a,b) and is found to predict the same behavior but without requiring the explicit storage of eye movement commands. (References: Arbib, M. A. and Didday, R. L. The organization of action-oriented memory for a perceiving system, Part I: The basic model. J. Cybernetics, 1971, 1, 3. Noton, D. A theory of visual pattern perception. IEEE Trans. System Science and Cybernetics, 1970, SSC-6, 349. Noton, D. and Stark, L. Scanpaths in eye movements during pattern. Science, 1971a, 171, 308. Noton, D. and Stark, L. Eye movements and visual perception. Scientific American, 1971b, 224, 34.)

61. Ditchburn, R. W., Fender, D. H., and Mayne, S. Vision with controlled movements of the retinal image. J. Physiol., 1959, 145, 98-107.

1. Retinal image movement is annulled by means of an apparatus which produces a visual target which moves so that its image remains on the same part of the retina despite movements of the eye. 2. It is found that imposed motion similar to the drift component of normal eye movements has little effect in preventing the "fade out" which occurs with a stabilized image. 3. Imposed motion similar to a natural flick produces a very sharp regeneration of the image which then fades out again. It is concluded that the flick motion plays a part in maintaining vision but is not the only effect operative in this respect. 4. Small amplitude imposed tremor motions also maintain vision, but the effect must rely on a summation over the whole frequency range of eye movement.

62. Duff, E. A. Atmospheric contrast transmission: Application to the visual detection and electro-optical lock-on problem. AFIT Thesis, June 1972, AD 743-560.

The contrast and size of the target limit detection or lock-on range models for the prediction of detection range are evaluated in this report. The contrast available at the eye or the electro-optical sensor is assumed to be the limiting factor. The atmosphere provides a transmission factor for the target-background contrast. A model for the prediction of contrast transmission proposed by Duntley in 1948 is examined. Duntley's work provides an analytic solution based on an equation which relates visibility to air-transmittance along an inclined path, and a table of air-ground ratios. An improved relation for visibility is developed by the author. More realistic sky-ground ratios are obtained from calculated data and from flight tests. The RRA Monte Carlo model and the ASW model, which predict contrast transmission, are compared for accuracy. The AWS model is also compared to recent flight data. The AWS model is shown to predict generally higher results than the RRA data, due to the approximations used. The AWS model does provide a useful, fast tool for prediction of contrast transmission. A more recent concept developed by Duntley, the directional path reflectance R*, is used to describe the atmospheric effects. R* provides a useful single parameter for evaluating a situation to determine approach angles where the effect of haze is a minimum. The directional background reflectance bRO must be used with R* to predict contrast transmission. Graphs illustrating the application are presented. The inherent target contrast is needed with the contrast transmission factor to predict detection or lock-on range. Measurements of inherent target contrast by photometric and photographic means are compared. A simple measurement technique for field use is recommended. Radiometric measurements are presented to illustrate some spectral effects which should be considered in comparisons between the eye and different electro-optical sensors.

63. Dugas, D. J. Target-search capability of a human observer in high-speed flight. USAF Project RAND, Memorandum RM-3226-PR, 1962.

Human observers continue to be an important factor in aerial reconnaissance, complementing the development of sophisticated sensors. In a search for relatively small targets, such as mobile missile carriers, the human eye may be the only detector with sufficient resolution and versatility to carry out a mission of reconnaissance with immediate strike capability. Although research on vision has been going on for many decades, it is interesting to note that the exact capabilities needed for target recognition under field conditions of reconnaissance have never been well defined.

In this memorandum the necessary conditions for the visual process are presented, and the modes of search are discussed in detail. One mode is an example of the familiar sector-scan pattern, and the other is a more specific method adapted to searching for rail-mobile targets. The limitations placed by speed and altitude combinations on visual performance in these two situations are summarized in figures. The curves shown in these figures represent the capabilities of an observer under ideal conditions; but in real search missions, allowances must be made for factors unique to the situation that tend to degrade the performance of the observer (e.g., fatigue, poor visibility, and vibration of the aircraft).

In comparing the two modes of search it was found that some of the difficulties encountered in searching for small targets can be alleviated by using an appropriate search pattern. It is important to acquire as much information as possible about the targets beforehand so that the observer can employ the most effective search procedures.

The human optical system apparently will not constitute the most serious speed limitations on the reconnaissance aircraft except at very low altitudes (less than 150 ft). It can be expected that structural limits of the aircraft will generally be encountered long before the maximum tolerance speed for vision is reached.

64. Duntley, S. The visibility of distant objects. Journal of the Optical Society of America, 1948, 38, 237.

The purpose of this paper is to identify the principal factors involved in the visibility of an object, to indicate how each factor affects the range of visibility of an object, and to supply charts which by combining these factors, enable the limiting range to be found under any set of prevailing conditions.

65. Duntley, S. Q., Gordon, J. I., Taylor, J. H., White, C. T., Boileau, A. R., Tyler, J. E., Austin, R. W., and Harris, J. L. Visibility. Applied Optics, 1964, 3, 549.

Calculations of the limiting performance of the human visual systems are based upon the separate properties of all of the physical components which, taken together, comprise a system for the transfer of information from the object to the observer's consciousness by way of the visual pathway. Thus, light reflected or generated by the object forms a body of image-forming flux which, after transmission through the intervening media, forms a retinal image which, in turn, is transmitted to the brain and perceived by the observer. In like fashion, the background against which the object is seen generates flux from a different part of object space, and this signal follows a corresponding path to the perceptual level of the observer. Discrimination of the object from its background depends upon the thresholds of the human visual system. Prediction of the limiting human visual capability to detect any specific object begins, therefore, with the optical properties of the object and its background. These, in combination with the nature of the incident lighting, define the inherent optical signal which is available in the direction of the observer. Assessment of the magnitude of this inherent optical signal is the first major step in any visibility calculation. It involves a considerable knowledge of the optical properties of both background and target as well as a detailed specification of their lighting.

66. Edwards, G. D. and Harris, J. L., Sr. Visual aspects of air collision avoidance: Computer studies on pilot warning indicator specifications. University of California, San Diego, Scripps Institute of Oceanography, Visibility Laboratory, February 1972.

This report describes techniques of computer calculations used to analyze the potential for improving visual acquisition of collision threats by means of Pilot Warning Indicator systems (PWI). It is a parametric study giving the quantitative effects of PWI resolution and effective range upon the average cumulative probability of detection.

67. Elkin, E. H. Target velocity, exposure time and anticipatory tracking time as determinants of dynamic visual acuity (DVA). Journal of Engineering Psychology, February 1961. (AD-256-891)

This paper was presented at the 32nd meeting of the Eastern Psychological Association in Philadelphia on 7 April 1961. The present study investigated the effects of varying angular target velocity on visual acuity for moving targets. This type of acuity has come to be known as dynamic visual acuity or, simply, DVA, which refers to the ability to discriminate small spatial separations in a target which moves with respect to an observer.

68. Enoch, J. M. Effect of the size of a complex display upon visual search. Journal of the Optical Society of America, 1959, 49.

This investigation is one of a series of studies designed to determine natural search tendencies during visual search tasks. In this study, 12 subjects were presented an ordered series of experimental aerial maps of different size. Their eye traces were recorded on a modified ophthalmograph while they searched for a specific critical detail. As was noted in other experiments of this series, coverage of the display was not uniform. In particular, greatest attention was paid to the center of the display. Search behavior in displays subtending 9 deg and larger at the eye remained essentially the same. For smaller displays, marked differences were noted. As the size of the display decreased, durations of fixations increased, interfixation distances decreased, concentration in the central area increased, and efficiency decreased. Efficiency is defined as percent of eye fixations falling within the display area.

69. Enoch, J. M. Natural tendencies in visual search of a complex display. Visual Search Techniques, Proceedings of a symposium, Publication 712, National Academy of Sciences, NRC Committee on Vision, April 1959.

In these studies, two classes of observers and two types of observation material were used. Trained photointerpreters viewed aerial photographs of varying scale and verticality, and non-trained observers viewed aerial maps simulating aerial photographs. The non-trained observers were drawn from the staff and students of Ohio State University. A modified ophthalmograph was employed. The search pattern is divided into at least two phases. The first phase we might call an orientation phase. During this phase the observer goes through a characteristic pattern in his search, which is repeated with remarkable similarity in every pattern executed by the same individual. One might call this the individual's basic, or general, search pattern. At the end of the orientation phase of the search, the individual would move to what might be called a specific search phase. If he had any clue or cues as to the location of the object of search, he would proceed to utilize these immediately after completion of the orientation pattern. If he did not have such aids to the location of the object, he would tend to expand upon the basic search pattern started in the orientation.

70. Enoch, J. M. The effect on visual search of the degree of generality of instructions to the photointerpreter. Report to Rome Air Development Center Air Research and Development Command, Griffis AFB, NY, 1958.

One of the main variables affecting a search pattern is the nature of the instruction given the photointerpreter. In this study, photointerpreters were asked to locate a class of objects. In two separate parts essentially identical findings were found. A less specific instruction results in a more generalized search pattern. However, the tendency to concentrate attention at the center of the display is strongly evident as are other biases. Marked differences in approach to a given problem and in ability to handle a given problem were found. They were discussed in terms of division of the work load of photointerpreters.

71. Erickson, R. A. Visual search performance in a moving structured field. Journal of the Optical Society of America, 1964, 54, 399-405.

The performance of 16 male observers who searched for an incomplete ring (Landolt C) among a number of solid rings in a square, moving field was measured. Search performance deteriorated as velocity or object density was increased; a target was more likely to be detected the closer it was to the center of the field; there was no significant correlation between the age of the observer and his search performance; there was significant correlation between foveal visual acuity and search performance in the moving field. The performance of the same observers on a previous series of tests is compared to their performance on the tests reported here. An hypothesis concerning the role of peripheral and foveal vision in searching for targets is advanced.

72. Erickson, R. A. Relation between visual search time and peripheral acuity. Human Factors, 1964, 6, 165.

An experiment investigated the relationship between peripheral visual acuity and time required to locate a target in a static structured display. Sixteen male observers were used in the tests. Peripheral acuity measured at 3.6 deg and 4.8 deg off the visual axis correlated significantly at the 0.01 level with time required to find a target in displays containing 16 or 32 rings and correlated at the 0.05 level with search time on displays of 16 and 32 blobs. Almost all correlations involving search times from object densities 48 and/or acuity measurements made at 6.0 deg off the visual axis were not significant. In addition to the results concerning peripheral visual acuity, other relationships between variables were suggested by analysis of the data. An analysis of variance established that the shape of the objects in the display (blobs or rings) and the number of objects in the display (16, 32, or 48) had a significant effect ($p < 0.01$) upon search time. The interaction of shape and object density was also found to be significant at the 0.01 level. There were no significant intercorrelations among observer age, foveal acuity as measured in a naval eye examination, and peripheral acuity. Furthermore, age and foveal acuity did not correlate significantly with search performance.

73. Erickson, R. A. Visual search for targets: Laboratory experiments. Aviation Ordnance Department, U.S. Naval Ordnance Test Station, China Lake, CA. NAVWEPS Report No. 8406, October 1964.

Visual search performance of 16 male subjects was measured and related to display- and observer-dependent parameters. Several factors emerged: a significant correlation exists between peripheral visual acuity scores and search-time scores for a search task in a static field. This correlation is dependent upon the angle of the visual axis at which acuity is measured and the number of objects in the field being searched. When the field is moving with respect to the subject, search performance decreases when the velocity of the field increases. Comparison of data from the dynamic experiment indicates that this performance degradation is due to time limitation and not to motion per se. Further, with velocity increase, foveal acuity becomes more important than peripheral acuity in the search task. Search time is proportional to the number of objects in the

display, and introduction of a linear cue into the display greatly decreases search time.

74. Erickson, R. A. Visual detection of targets: Analysis and review. Aviation Ordnance Department, U.S. Naval Ordnance Test Station, China Lake, CA. NAVWEPS Report 8617, February 1965.

This report discusses many of the aspects of air-to-ground visual search for targets. Curves are presented that can be used for estimating the probability that a ground target is within view and for determining the angular rate of target as measured with respect to the air observer. Optical aspects (clouds, atmospheric attenuation, reflectance factors) of visual detection are discussed briefly and references from which data can be obtained are cited. A number of laboratory experiments concerning visual detection are described, and some of the results are given. Examples of simulation, operational, and mathematical methods of obtaining estimates of search performance are given and compared.

75. Erickson, R. A. Comparison of visual search by pilots and high school students. _Perceptual and Motor Skills_, 1966, _23_, 923-928.

Data were obtained on the search time required by high school senior boys to find a target in structured, abstract displays presented at three visual noise levels. It was found that the rank ordering of performance on the three noise levels was the same for these 12 subjects as for 22 Navy pilots tested earlier. Also, the students had effectively the same absolute performance as the pilots. This study provided the basis for the decision to use high school senior boys in future experiments of this type when pilots were not available. Data were also obtained from the 12 subjects on four foveal-acuity tests. The scores on three of the tests showed significant correlations with one another. Scores on the fourth test (Bausch & Lomb checkerboard) did not correlate with scores from any of the other three.

76. Erickson, R. A. and Burge, C. J. Modeling air-to-air visual search. Naval Weapons Center, China Lake, CA, Report No. NWC TP 5709, October 1974.

The development of new aircraft, weapons systems, and tactics requires knowledge of aircrewman performance

and limitations. One of the performance estimates required in analysis of air-to-air combat is the range at which other aircraft are visually detected by a pilot or other aircrewman. The methodology used in obtaining such estimates ranges from actual flight tests to mathematical modeling. The latter process is popular because of the lower cost and ease of obtaining "data." There are, however, hazards in modeling human visual performance that sometimes are not known by mathematicians or systems analysts. The report discusses visual detection data requirements and the limitations to the methods of obtaining these data. A model is also described, as an illustration of the modeling process. The report is intended to supply background information to those working in the quantification of human visual performance in air-to-air environments.

77. Erickson, R. A. and Gordon, J. I. Field evaluation of a 1962-vintage visual detection model. Report No. NWC TP 5057, Naval Weapons Center, China Lake, CA.

The range at which US Navy pilots could detect and recognize olive-drab vehicles parked on a light-brown, graded strip in the desert was measured by flight tests conducted in 1962. Scripps Visibility Laboratory measured light transmission through the aircraft windscreen and the atmosphere. Vehicle and background luminance measurements were also made. These measurements were used by Scripps as inputs to a mathematical model to compute detection and recognition range. Computed detection ranges were within at least 15 to 29% of those measured in the flight tests. Computed recognition ranges, however, were about three times as great as those measured in the field. This report does not represent current Scripps modeling techniques. It should be considered useful principally for the field data presented, and for the historical information on mathematical modeling of the visual process.

78. Ferguson, J. C. and Goodson, J. E. A description of the air-to-air visual acquisition task. Aerospace Psychology Technical Memorandum 72-2, Aerospace Psychology Dept., Naval Aerospace Medical Research Laboratory, Pensacola, FL, November 1972.

The goal of this effort is to specify pertinent mission-related information which is required for a description of the air-to-air detection and acquisition task as it occurs in the fighter and attack communities of the US Navy. Such a description was requested by Working Group 40 during its meeting of 10-12 October 1972. This report is primarily responsive to the items and format generated during that meeting. The primary sources for this report were: (1) specifications, descriptions, and standards for relevant aircraft, equipment, and personnel, and (2) interviews with 12 fighter and attack pilots recently returned from southeast Asia. The interview data have a major weakness and a major strength. The weakness is that the data related to variables such as detection ranges, altitudes, and headings are based upon pilot estimates, not accurate measurements. The strength of the interviews is the fact that these data came from the combat environment.

79. Ford, A., White, C. T. and Lichtenstein, M. Analysis of eye movements during free search. *Journal of the Optical Society of America*, 1959, *49*, 287-292.

The positive polarity of the human cornea was used to produce signals from marginal electrodes around the eyes. The potentials were amplified with DC networks which produced amplitude-time oscillographic tracings of the horizontal and vertical components of eyeball movement, and also controlled the deflectors of a cathode ray oscilloscope (CRO) in such a way that the beam moved in the same way as the eyes. An automatic camera photographed the CRO face to produce two-dimensional electro-oculographic (EOG) plots of eyeball movement. Data thus obtained were used for an analysis of eye movement and fixations in a surveillance search test. The paper oscillographic tracings against time show (1) the number of fixations per unit of time, and (2) the duration of the fixations. The cathode-ray EOG shows (1) the order of fixations in search procedure, (2) the lengths of various saccadic jumps, and (3) the areas of neglect and concentration for 5-s search periods on a circular field subtending 30 deg of visual angle.

80. Fowler, F. D. and Jones, D. B. Target acquisition studies, final report. Prepared for Engineering Psychology Branch, ONR, Washington, D. C., April 1972.

This report presents the final results of studies to obtain baseline data about human target acquisition performance. Factors considered crucial to the acquisition problem were varied parametrically while others were held constant. The results are reported in five major phases corresponding to organization of

the investigation into particular areas of concentration.

81. Fox, J. N. and Lyman, J. Structureless field visual perception studies: Applications to automotive and aerospace safety research. Presented at 14th Annual Meeting of the Human Factors Society, 12-16 October 1970, San Francisco, CA.

The results of a study investigating factors which influence human visual perception of movement and direction of movement in structureless fields are presented. Independent variables included speed and direction of the target's movements, presence of a limited reference frame, target size, and initial target position. Presence of the reference greatly increased the number of correct responses to both moving and motionless targets. Increasing target velocity and area ratios also affected performance. For the velocities investigated, perception was much better for relative motion than for absolute motion. Subjects often perceived motion but misinterpreted its direction, and would often score absolute motion of both targets incorrectly, but score the relative motion between them correctly. The perception of motion and its direction in stark environments is a complex function of the total dynamic and structural aspects of the entire visual field. Possible technological extensions in automotive and aerospace safety research are also discussed.

82. Frezell, T. L, Hofmann, M. A., and Oliver, R. E. Aviator visual performance in the UH-1H, Study I. US Army Aeromedical Research Laboratory Report No. USAARL-74-7, October 1973.

This study monitored, via the corneal reflection technique, visual performance of Army aviators while flying a number of maneuvers in a UH-1H. Visual performance, to include time and transition information, was gathered over 13 cockpit areas. In addition to the objective recordings, subjective assessment by the aviators with regard to their visual performance was also attained. Results acquired by both techniques are provided.

83. Gasson, A. P. and Peters, G. S. The effect of concentration upon the apparent size of the visual field in binocular vision, Parts I and II. _The Optician_, 1965, January 1 and January 8.

Twenty subjects were examined. Their field shrinkages were expressed as a percentage of their normal visual field. For each subject a mean figure was calculated from all of the individual measurements. Eighteen of the twenty results were greater than Kephart and Chandler's critical figure of 8.7% showing that the majority of subjects underwent a significant reduction of the vision span under conditions of extreme concentration.

Part II, Summary: The peripheral binocular visual field was measured for 20 subjects, first using central fixation and then while concentrating upon operating a hand-eye coordination task. Results showed: (1) There is a significant shrinkage in the visual span during concentration. (2) The phenomenon is probably cortical rather than retinal. (3) The phenomenon is a transient adjustment to the stress of concentration.

84. Gilmour, J. D. A systematic approach for prediction and improvement of target acquisition performance. Target Acquisition Symposium, Office of Naval Research, Naval Training Center, Orlando, FL, 14-16 November 1972, pp. 177-186.

A representative example is cited of the coordinated use of complementary research methods to systematically improve quantitative prediction and operational performance in target acquisition. A modeling concept is described that provides for the organized treatment of problem parameters and the identification of leveraged parameters offering significant improvement in prediction and/or performance. Illustrative applications of analysis, simulation, laboratory testing, and field test validation are then used as examples of how prediction capabilities and system performance can be improved relative to the parametric implications of existing models. The examples used are scaling and classification of target backgrounds, and head-up target predesignation using onboard navigation system information.

85. Goodson, J. E. Air-to-air visual acquisiton of targets: Problem definition and approach. Aerospace Psychology Technical Memorandum 72-1, Naval Aerospace Medical Research Laboratory, Pensacola, FL, April 1972.

The problem of air-to-air visual acquisition is reviewed in terms of its criticality, and the stimulus characteristics which contribute to degraded performance. Little data are available concerning air-to-air acquisition performance, and even less data are available which relate specific visual mechanisms directly to air-to-air acquisition. It is clear, however, that acquisition normally occurs at distances far short of the detection range, and that many targets go undetected even though they pass well within acquisition range. It appears that the most critical stimulus characteristic is the poorly structured background, and that the major problem peculiar to air-to-air acquisition concerns the adequacy of search and accommodation in this poorly structured field. Methodologies and techniques for measuring visual acquisition performance are readily available. However, these have not been applied to assess visual acquisition capabilities for Navy-specific problems. Recommendations are made for the development of baseline data, and for relating laboratory tests to these data as potential selection criteria. Three training techniques are discussed, and two of these are recommended for validation studies. The possibility of developing an automatic scanning marker is discussed.

86. Goodson, J. E. and Miller, J. W. Dynamic visual acuity in an applied setting. Aerospace Medicine, 1959, October, 755.

In summary, we would make the following points. 1. Visual acuity deteriorates in the air with increased target speeds in much the same manner as it does in the laboratory when similar targets are used. 2. The rate of deterioration in acuity, when using two targets, seems to take a linear form over the range of speeds used as opposed to the curvilinear form taken when one target is used. 3. Deceleration of target speeds has a marked effect on performance of a visual tracking task because of both the change in speeds and the resulting change in configuration of the target. The effect appears to be beneficial. 4. Physiological factors peculiar to the flight conditions either did not affect performance, or else acted in a consistent manner. 5. Anxiety toward flight, as measured by proneness to become air sick, did not have an effect on performance of the task. 6. All three methods used for testing dynamic acuity discriminated between subjects significantly at all speeds. 7. While there was considerable learning in the one-target method, no learning took place when the more complex target was used.

87. Gordon, J. I. Predictions of sighting ranges based upon measurement of target and environmental parameters. U.S. Naval Ordnance Test Station Report, 1963.

During the summer of 1962, a field experiment was conducted at the U.S. Naval Ordnance Test Station, China Lake, CA. This field test consisted of a coordinated program of visual sightings and measurements of the environmental and target properties appropriate to the observations. The specific task undertaken by the Visibility Laboratory was to aid in the design of the experiment to obtain the observations, to conduct the program of measurement of the environmental and target properties, and to use these data to predict the sighting ranges. This report contains a description of the design of the visual experiment, the details of the program of geophysical measurement, and the predicted sighting ranges. The observed sighting and recognition ranges will be published in a separate report by the Naval Ordnance Test Station.

88. Graham, W. Aircraft pilot warning instrument (APWI) study. Department of Transportation, Federal Aviation Administration Report No. FAA-RD-75-59, March 1975.

The factors by which the expected number of collisions could be reduced by the implementation of Proximity Warning Instruments (PWI) having various performance characteristics are estimated. If both aircraft involved in an encounter are equipped with high performance PWI (sharp range and altitude cutoffs, and 2 deg relative bearing accuracy), then it is estimated that the expected rate of collision could be reduced by factors of 10 or more at typical closing rates. See-and-avoid itself is estimated to be highly effective, as judged by the number of potential collisions that are avoided, but the residual collision risk is unacceptable to the public and large effort is being made to mitigate it. The collision risk per operation tends to increase as the square of the number of operations so that the cost of providing separation assurance per operation will ultimately limit the growth of traffic unless technological progress provides more economical solutions. Collisions involving general aviation aircraft cause a very small fraction of general aviation fatalities and represent a very difficult technical problem because most of these collisions occur in traffic patterns where the angular coverage and associated display requirements are severe for airborne equip-

ment solutions and the aircraft are likely to be outside the coverage of ground based equipment solutions. For the typical general aviation aircraft, the principal effect of collision risks appears to be the operational and cost burdens of minimizing the risk to instrument flight rule (IFR) operations.

89. Greening, C. P. The likelihood of looking at a target. Air-to-Ground Target Acquisition, AGARD Conference Proceedings No. 100, June 1972, Brussels, Belgium.

Visual search behavior is characterized by brief glimpses of the terrain, separated by rapid eye movements, or saccades. The likelihood of looking at the target with any particular glimpse is, in most models of search behavior, assumed to result from either random motion or a mechanically systematic search pattern. In the present study, it is assumed that the observer uses extrafoveal vision to evaluate the terrain before each saccade, to maximize the likelihood of looking at the target. Quantitative data on extrafoveal search, obtained in a different context by Williams, show that such behavior is lawful and predictable. The results are here applied to dynamic air-to-ground search, yielding target acquisition predictions which compare favorably with those obtained by other methods.

90. Greening, C. P. Target acquisition model evaluation: Final summary report. Autonetics North American Rockwell Report No. NWC TP 5536, August 1973.

The purpose of the study was to draw together existing visual, air-to-ground target acquisition models, describe them, and compare them. Six models were selected for detailed study; a larger number were described briefly, especially in terms of unique features. The descriptions of the selected models include structure, relationships to other work, EDP requirements and validation data. Comparisons were drawn in terms of variables incorporated, type of output, sensitivity to variables, range of applicability, evidence of validity, and EDP requirements. Conclusions and suggestions for further work are included.

91. Greening, C. P. Target acquisition model evaluation. Part 2. A review of British target acquisition models. Autonetics Division, Rockwell International Report No. NWC TP 5536, August 1974.

The purpose of the study was to extend an earlier summary and evaluation of six target acquisition models to two major British modeling efforts, and of the modifications made to one of the earlier models by Battelle Laboratories. The descriptions of the selected models include structure, relationships to other work, and validation efforts. The models were compared with the six earlier reviewed in terms of included variables, type of output, sensitivity to variables, and range of applicability.

92. Greening, C. P. Mathematical modeling of air-to-ground target acquisition. Human Factors, 1976, 18, 111.

Six principal models of air-to-ground target acquisition modeling and prediction are described in a common format and are compared in terms of structure, types of sub-models, unique features, and evidence of validity. Sensitivity to variables is examined semi-quantitatively. Most of the models share certain features, such as (1) strong emphasis on purely optical elements of target acquisition with corresponding neglect of cognitive factors, (2) reliance on laboratory data rather than field data for sources of sub-models, and (3) limited evidence of overall validation. The implications of the characteristics of existing models for current applications and for possible future work are discussed.

93. Greening, C. P. and Wyman, M. J. Experimental evaluation of a visual detection model. North American Rockwell, Inc., Autonetics Division, T6-3224/501, 3 January 1967.

A fixed-base simulation experiment was performed to gather visual air-to-ground target recognition performance data for comparison with predictions from the Autonetics Detection Model. Color motion picture imagery obtained during low-altitude flight was used to simulate the observer's forward view. Observer performance was measured in terms of probability and range of correct target recognition. The A-D Detection Model incorporates parameters related to the target, the environment, and the observer. In generating theoretical predictions from the model, values of all parameters were specified independently of the data obtained in the experiments. No curve fitting techniques were used to improve the fit between the empirical and theoretical curves. Results indicate a close relationship between the obtained performance data and the model predictions. A product-moment correlation of +0.53, significant at the 0.001 level, was obtained between the empirical and theoretical 50% recognition ranges.

94. Grether, W. F. Visual search in the space environment. Human Factors, 1963, 5, 203.

Among the important tasks of an astronaut will be the visual search for other vehicles in a co-planer orbit for purposes of rendezvous. Human data for minimum visual acuity can be used to compute the maximum sighting distance using information about target size, background, luminance, and target contrast. But this distance is valid only if the astronaut knows the exact location of the target satellite and can fixate on it with foveal vision. For a dynamic search situation, it is more meaningful to compute a probability of sighting using additional data or assumptions about peripheral visual acuity, eye fixation frequency, search area, and target closure rate. A method is described for computing probability of sighting. An example is provided for application of the method to a search situation for the approximate situation of a space rendezvous with a target comparable to the NASA Gemini vehicle.

95. Grossman, J. D. and Whitehurst, H. O. Effect of visual acuity on target acquisition. NWC TP 5884, June 1976.

Two laboratory experiments were conducted. The purpose of the first experiment was to determine the effect of far visual acuity on target acquisition performance relative to 10 other factors. A rank ordering was achieved by employing a screening technique (partial factorial). Far visual acuity ranked second behind slant range in most analyses. The second experiment was conducted to generate curves which related search times and detection probabilty to far visual acuity at different levels of slant range, masking, and observer experience. A full factorial design was employed to test the factors. Subjects with better than 20/20 acuity located the targets at least twice as fast as subjects with 20/40 and 20/50 acuity. It was also found that the effect of far visual acuity depended upon the observer-to-target range and upon the extent of target masking.

96. Gutmann, J. C., Snyder, H. L., Farley, W. W., and Evans, J. E., III. An experimental determination of

the effect of image quality on eye movements and search for static and dynamic targets. Wright-Patterson AFB, OH: Aerospace Medical Research Laboratory, AMRL-TR-79-51.

This report contains the results of two experiments which investigated the effects of the quality of a televised image on eye movements and search-related dependent measures. The first experiment search task involved having subjects perform an air-to-ground search during a simulated flight.The quality of the image presented was varied by either passing, low-pass filtering, or attenuating the video signal and by adding electrical white noise to the video signal. The results of this experiment indicate that (1) at the highest level of electrical noise added, the percent of correct target acquisitions was decreased moderately, (2) the larger the target, the higher the percent correct responses, (3) the low-pass filtering of the video signal led to shorter ground ranges at acquisition for the large-sized targets, and (4) that the larger the target, the longer the fixation duration. Low to moderate correlations between modulation transfer function area (MTFA) and performance measures generally indicated that as MTFA increases performance improves, and that as MTFA increases fixation duration decreases. The search task of the second experiment consisted of having the subjects search for a designated letter or numeral across a televised picture of randomly positioned letters and numerals. The quality of the picture was varied by either passing, low-pass filtering, high-pass filtering, or attenuating the video signal and by adding electrical white noise to the video signal. The results of this experiment indicated that (1) the high-pass filtered high noise level condition led to significantly longer search times; and (2) the fixation times associated with the high-pass filtered condition were longer than those associated with the low-pass filtered, attenuated, and unfiltered unattenuated conditions, and that this effect was most pronounced under high noise level conditions. Correlations between MTFA and performance measures indicated that increases in MTFA lead to decreases in search time and decreases in fixation duration.

97. Hansen, O. K. and Frugard, J. S. Abstracts of literature relevant to airborne operator target recognition training. Autonetics, North American Rockwell Technical Report, 1967.

This document contains a select set of references and abstracts relevant to the topics of visual reconnaissance training and high resolution radar operator training.

98. Hansen, O. K. and Offenstein, R. E. Parametric analysis of tactical target recognition performance: Comparison of experimental training data and JTF-2 field studies. Autonetics, North American Rockwell Technical Report, April 1969.

Reported here are the results of a target recognition error analysis based upon the data derived from two sources. The sources were (1) the Joint Task Force Two field tests, and (2) an experimental target recognition training research (AOT) program. This latter program employed visual simulation techniques based upon cinematic film of the same target sites used in the JTF-2 target acquisition field tests. The analyses reported here compared and contrasted the field test and simulation training data to: (1) Determine probability estimates of various target recognition errors and to relate these estimates to types of reconnaissance aircraft, sensor devices, and observer characteristics; (2) Develop comparative scales of target recognition difficulty for the sensors, aircraft, and personnel of the JTF-2 and AOT programs; (3) Develop estimates of the relative effects of target recognition training upon personnel performance. Target acquisition and recognition error data were tabulated in "Confusion Matrix" formats and error probabilities were estimated for each of 19 types of target and each of 5 sensor-aircraft viewing modes. The viewing modes included: (1) A simulated visual reconnaissance mission based upon dynamic wide-screen cinematography; (2) A simulated mission based upon static projection of a series of color slides; (3) Reconnaissance image interpretation of standard photographs and infrared sensor data; (4) In-flight observation from 01-E aircraft; (5) In-flight observation from A-4C aircraft; (6) In-flight visual observation from UH-18 helicopter. Statistically significant differences in recognition-error patterns were found between and among viewing modes. Implications for both training and operational planning were discussed.

99. Hansen, O. K. and Wood, M. E. Airborne operator target recognition training procedures, Vol. II: Visual reconnaissance study. Technical Report AFHRL-TR-69-36, Wright-Patterson AFB, OH, 1969.

The results of the second phase of the Airborne Operator Target Recognition Training Program are presented. The purpose of this phase was to conduct an experimental evaluation of alternative training procedures designed to develop the target recognition skills of airborne observers. The experimental evaluation was based upon a complex study in which three training variables were compared in factorial combinations to determine the most effective mixture of training content and procedure. The variables were: (1) two levels of introductory audio-visual material with differential emphasis on theory of function of the human visual system (one level stressed psychophysiological theory and the other level stressed the practical principles of use of the visual system), (2) two levels of target signature training (one level stressed specific cues for target identification and the other level stressed comparison of similar targets without reference to individual cues), and (3) two levels of training in visual search technique (one level employed a wide dynamic field during search instruction and the other employed a narrower static field). The study employed a semi-automated training system and a visual flight simulator for final test comparisons. Experimental subjects were selected from a college student population having the physical, biographical, and psychological characteristics of USAF flight trainees. Results of the study were interpreted in three contexts. One related to the formal data interpretation. Another related to the practical problems of training military personnel in tactical target recognition, and the third context related to training research methodology. It was concluded that the most effective training program was the one that included the psychophysiological vision material in combination with the instruction of specific target signatures and narrow field static search. It was also concluded that new methods are needed to incorporate practical military considerations such as training cost, personnel availability, and operational relevance into the research decision strategy. Some of these considerations were explored and a list of practical training research limitations was formulated. Finally, it was suggested that training research can be more efficient if computerized systems are employed to provide on-line analysis of experimental training results. This approach was compared with the more traditional methods in which the entire study is run prior to data analysis.

200. Hansen, O. K. and Wright, W. E. Airborne operator target recognition training procedures. AF Human

Resources Lab and the Avionics Laboratory, Wright-Patterson AFB, Ohio, Technical Report AFHRL-TR-69-34, March 1969.

The results of the first phase of a research program to develop target recognition training procedures for airborne observers are presented. This phase has been concerned with the analytic development of an experimental research plan for studies in visual observation training. Results of the analyses are described, and a detailed plan for the initial training experiment is presented.

101. Harcum, E. R. Detection versus localization errors of various radii of the visual field. Visual Search Techniques, Proceedings of a Symposium, Publication 712, National Academy of Sciences, NRC Committee on Vision, April 1959.

The problem of this paper is to distinguish between two factors affecting accuracy of reporting the location of a target, which may appear tachistoscopically on a radius of the visual field eccentric to fixation. Whenever the observer is asked to report the radial location of such a target, two of the factors affecting performance are, first, the capability of detecting the presence of the target by the observer, and, second, the ability of the observer to localize correctly the target once he has seen it. Let us call the first, "detection sensitivity," and the latter, "localization accuracy." The present thesis is that detection sensitivity is greatest for targets to the right and left of fixation, and poorest for those targets above and below fixation, but that localization accuracy is best for targets above, below, right, and left of fixation, and poorest for those targets diagonally displaced from fixation.

102. Harris, J. L. Factors to be considered in developing optimal visual search. Visual Search Techniques, Proceedings of a Symposium, Publication 712, National Academy of Science, NRC Committee on Vision, April 1959.

The capability of performing successful visual search calculations involves essentially two factors. The first is the availability of all necessary visual psychophysical data. This is a large order for the psychophysicist in this field. The second factor is the development of proper tools for the analysis of the task. This development of tools involves elements of operations analysis, statistical decision theory, and detection and search theory. Because much of the psychophysical data existing is nonanalytic in nature, work is required in developing analytical approximations, where feasible, and graphical and computational aids, where the analytic approximations are not feasible.

103. Harris, J. L. Studies of mathematical models of visual performance capability. Scripps Institute of Oceanography, University of California, San Diego Technical Report, January 1963.

This report summarizes the pertinent results to date of an extended series of interrelated studies of mathematical models o. visual performance capability. The starting point for the studies is the derivation of an analytical expression for the psychometric function. The subsequent studies involve the use of the analytic psychometric function as a tool for the prediction of the results of vision experiments which either have been performed or could be performed. The capability of making such predictions constitutes an important forward step toward an operational Visual Target Classifier System. In addition to the prediction of visual thresholds, the model can be used to explore the significance of currently employed techniques for the processing of experimental vision data.

104. Harris, J. L. Visual aspects of air collision. <u>Visual Search</u>, Symposium conducted at the spring meeting 1970, Committee on Vision, Division of Behavioral Sciences, National Research Council, National Academy of Sciences, Washington, D. C., 1973.

The material presented in this paper illustrates a technique of calculation applicable to the air collision problem. No conclusions can be drawn from a single case involving one aircraft, one aspect, one lighting geometry, one search solid angle, or any other single instance of a wide variety of conditions. Similar analysis performed for a cross-section of such cases will give insight into the nature of the visual capablities in air collision avoidance. As is generally true, it is difficult to postulate a practical solution to a problem that is not clearly understood. In my opinion, the tools of analysis described in this paper can assist in developing such an understanding. It is very easy to attribute every air collision to "pilot error."

To do so may be placing an unjustified stigma on the pilots involved and may allow all other pilots to continue a false optimism that it can never happen to them. A clear understanding of the capabilities and limitations of the human visual system in collision avoidance with full recognition of the pilot's cockpit workload is a necessary prerequisite for the development of satisfactory solutions to the problem.

105. Harris, T. J., Jacobs, B. J. and Strauss, W. J. Air-to-air combat model program and appendices, technical details, ATAC-2: Single search and double search. Caywood-Schiller Associates, Chicago, IL, Technical Report, November 1967.

ATAC-2 is a simulation model designed to help evaluate fighters in air-to-air combat. The model treats the one versus one dogfight which arises from a random search situation. Both aircraft in the combat are usually aggressive. The two principal outputs from the model are the probability a given aircraft is killed in the fight and the expected number of enemy aircraft kills over its useful life. Combat is restricted to a fixed altitude. The maneuvers are dynamic in that each aircraft responds to the situation at each moment in a duel, depending on the information it has about an opponent's activities. Inputs include, for each aircraft, search and tracking radar characteristics, passive radar sensors, optical capability, IFF, energy-maneuverability data, weapon loadings, weapon characteristics, and weapon kill probabilities. The rationale for model specifics are presented. Flow charts and program listings are included. The model has been run repeatedly on an IBM 7094.

106. Hart, R. S. Effects of colored lenses on visual performance. Aerospace Medical Research Laboratory, Technical Report No. AMRL-TR-74-38, 1974.

This study compares operator target detection performance while wearing red, yellow, and gray sunglass lenses and unaided viewing. A research task was performed outdoors using survival orange tents located at ranges of 1600 ft to 4500 ft from the subjects. No statistically significant performance differences were obtained, although subjectively the operators preferred the yellow lenses over the gray sunglasses and unfiltered conditions.

107. Heap, E. Mathematical theory of visual and televisual detection lobes. Journal of the Institute of Mathematics and Its Applications, 1966, 2, 157.

This paper reviews recent developments in the application of mathematics to the evaluation of human visual performance. Although the spread of automation is proceeding fast, in the modern world of technology there remains a continued need for the human being to monitor and supervise many systems processes. Also the human eye is still the best detection device in many circumstances, some of which, it is shown, can be represented mathematically. Thus, the visual aspects of man's capability are inevitably involved as part of current man-machine systems. Furthermore, television is coming into wide usage as an aid to detection and supervision, since it enables the observer to sit remotely from the viewing situation, which might either be dangerous or inconvenient. Mathematical extensions of visual detection models into the television mode are also given, showing the advantages that can be obtained from magnification and contrast enhancement effects in comparison with the disadvantages of restricted fields of view and limited resolution. A first step is taken, therefore, toward expressing some important human factors in mathematical form.

108. Henneman, R. E. Factors determining the identification of ambiguous visual stimuli. Visual Search Techniques, Proceedings of a Symposium, Publication 712, National Academy of Sciences, NRC Committee on Vision, April 1959.

One of the more serious problems of visual search concerns the difficulty of target or signal detection and identification because of ambiguous stimulus data. Such stimulus ambiguity may arise from several conditions, such as masking, distortion, or impoverishment. These adverse conditions, frequently encountered in operational situations, lead to delays and inaccuracies of the perceptual responses of the observers. Since little can be done in practical situations to reduce the physical sources of stimulus ambiguity, there arises the significant question of whether it may be possible to alter the state of the observer so as to improve his perception under such conditions. To what extent may greater operator proficiency be achieved by providing him with a stock of built-in responses, thereby enabling him to act independently of the physical stimuli? The notion of multiple determination of perceptual responses and the closely related concept of "set" offer suggestive leads toward the answer to this question.

109. Hesson, J. M. and Thomas, F. H. Training materials for aerial observer instrumentation in basic visual skills. HumRRO Technical Report No. 80, October 1962.

The material presented in this paper is designed to assist the unit training officer in developing and presenting a complete training package on the basic skills of visual aerial observation. The material is broken down as follows: Period 1 (2 hrs.), Visual Search Techniques; Period 2 (6 hrs.), Recognition Training; Period 3 (4 hrs.), Geographical Orientation; Period 4 (4 hrs), Target Location.

110. Howarth, C. I., Bloomfield, J. R., Kemp, J. F. and Mathews, M. L. Visual detection and search. Ministry of Technology Report of Contract No. PD/24/018/AT, July 1966-June 1967.

By investigating the effects of various factors on visual detection, we hope to help with the prediction of the levels of performance obtainable in real life detection tasks. Positional uncertainty of the target, the structure of the field of view, and movement were specified because of their relevance to practical search situations and because of the lack of reliable laboratory data. To help develop an adequate understanding of visual search behavior, we have begun to look at some of the above parameters, under conditions where the observer is allowed only a single, brief glimpse of a display and also under search conditions (i.e., where he is allowed to look around the display until he finds the target). We hope to be able to use our data to test the models of visual search which are currently in use or, if these prove inadequate, as the basis for new models.

111. Howarth, C. I. and Bloomfield, J. R. Toward a theory of visual search. AGARD Conference Proceedings, No. 41, A.2, October 1968.

As part of a fuller program of research into the nature of visual search, we have devised a simple, adaptable search task in which subjects look for the odd disc in a display of larger or smaller discs.

We have carried out extensive studies of well practiced observers, producing much basic search data. We have derived a model of search from basic search theory which, while being in no way definitive, is mathematically simple, and, to some extent, accounts for the data we have found experimentally. However, there are some problems, and this is not more than a first step in a continuing effort to devise ways of predicting the range and latency of real targets from a physical specification of the target-background complex.

112. Hughes, R. J., Henke, A. H. and Schultz, R. L. et al. Helmet-mounted sight/display applications, vol. III, Tracking capabilities. AF Flight Dynamics Laboratory, Wright-Patterson AFB, OH. Technical Report AFFDL-TR-69-118, 1969.

This report describes the system studies and experimental work done to determine the applicability of a helmet-mounted sight display (HMS/D) to high-performance aircraft of the F-15 type. The HMS/D was found to have several areas of applicability to such aircraft, particularly in the mission phases having to do with weapon delivery. Closed-loop performance of the sight display combination was examined experimentally as a part of the study. The performance experiment is based on the ability of the engineer subjects to sight and track targets displayed on the helmet display. Interface of the HMS/D with other aircraft systems was considered, and a baseline HMS/D system was defined to the degree necessary to enter a prototype development phase.

113. Ireland, F. H. Effects of surround illumination on visual performance: An annotated bibliography. Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, OH. AMRL-TR-67-103, July 1967.

A common human factors recommendation states that, for good target visibility, the area surrounding a display should not be brighter than the background area within the display. However, this recommendation must often be violated in applications where the surround brightness cannot be adequately controlled (e.g., in an airplane cockpit) and/or display technique limitations prevent use of high brightness backgrounds (e.g., with cathode ray tube). This literature review was undertaken to see

what has been discovered thus far concerning the effects on target visibility of specific parameters of a surround-to-background relationship in which the surround is brighter than the display background. Well over 100 documents were reviewed. Seventy-five annotated references to the more pertinent documents are contained in this report. From this review it would appear that the important parameters determining the visibility of a target, of a given angular subtense at the eye and centered on the display background, are (1) target-to-background contrast, (2) background brightness, (3) background angular subtense (which determines target-to-surround separation), (4) surround-to-background brightness ratio, and (5) surround angular subtense (important when the surround does not extend to the outer limits of the visual field). Quantitative effects of these parameters have been studied by numerous investigators. Results of studies using extended surrounds, rather than point sources, have not been sufficiently comprehensive or consistent to support quantitative generalizations in this area. Attempts have been made by Holladay and by Moon and Spencer to make quantitative predictions for the extended surround case on the basis of the more extensive body of data dealing with point source effects. However, several of the findings upon which their formulas were based have been contradicted by other findings cited in this report

114. Johnston, D. M. Search performance as a function of peripheral acuity. Human Factors, 1965, 7, 527.

This study was made to investigate the relationship between the size of visual fields of observers and time required to locate targets on static displays. The findings, which indicate that people with large visual fields can find targets more rapidly than observers with small fields, have practical selection and training application. Equations are presented which can be used to determine search time that can be expected as a function of the size of the visual field of the observer and the apparent size of the area being searched.

115. Johnston, D. M. Effect of smoking on visual search performance. Perceptual and Motor Skills, 1966, 22, 619-622.

The purpose of this exploratory study was to determine what effect no smoking or reduced smoking had on time required to find a target on static displays. Four males served as subjects in the experimental group and four in the control groups. Search performance improved 34% for a group of habitual smokers who reduced their smoking or abstained from smoking for 2 weeks. In contrast, search performance improved only 6% for the control group of smokers and 25% for the control group of nonsmokers. Although only a few subjects were measured, results indicate further study should be made.

116. Johnston, D. M. The relationship of near-vision peripheral acuity and far-vision search performance. Human Factors, 1967, 9, 301.

Thirty-five subjects who did not wear glasses or contact lenses and with foveal acuity of 20/30 or better monocular and binocular far and near vision were given a near-vision peripheral acuity test and a far-vision search task. The results, which showed a low correlation between near-vision peripheral acuity and far-vision search performance, are consistent with Giese's findings of low correlations between near and far foveal acuity.

117. Jones, D. A. Visual search processes of Coast Guard aircrewmen. Naval Postgraduate School, Monterey, CA, Master's thesis, December 1974. (AD/A004-252)

This thesis presents the various components of the visual search process as it applies to Coast Guard lookouts. It begins with a description of the human eye and follows with an introduction to detection lobe theory. Next, the most distinct region of daylight vision, the foveal vision area, is discussed. In the following section on eye movement patterns during visual search, the rate and duration of eye fixations are graphically presented. These data indicated that there are about three fixations every second and each fixation lasts about a quarter of a second. The probability of seeing section indicates that the probability of detection in the foveal vision area is proportional to the size and contrast of the target. Finally, the inverse cube law of detection is utilized to calculate the probability of detection versus coverage factor for patterned searches.

118. Jones, D. B. and Bergert, J. W. Target acquisition studies: Visual angle and target to background con-

trast for directly viewed targets. Martin Marietta Corporation, Orlando, FL, Technical Report.

This study investigated the basic target acquisition capability of the unaided eye in a simulated, closely controlled, real-world environment. Pilot performances on air-to-ground target detection and recognition tasks were examined in (1) a search task for unbriefed targets and target areas, and (2) psychophysical threshold visual angle requirements for briefed targets. A large decrement in performance at low contrast levels of 5% to 15% for both target detection and recognition was found. Differences in performance between search and threshold tests decreased to a constant value above approximately the 20% contrast level. At low target to background contrast levels, high contrast non-targets were eliminated prior to reaching the visual threshold for the low contrast target which was then detected. Consequently, there were no significant differences between search and threshold tasks at low contrast levels. Comparison of the static and dynamic threshold tests revealed no differences in the observer's performance with limited or unlimited time for target examination.

119. Jones, D. B. and Freitag, M. Recent target acquisition and recognition studies. Martin Marietta Corporation, Orlando, FL, Technical Report.

This study investigated the basic target acquisition capability of the aerial observer using a TV display system in a simulated, closely controlled, "real-world" environment. Pilot performances on air-to-ground target detection and recognition tasks using TV were examined in static and dynamic viewing conditions. Two fields of view (FOV) for 14.5 deg and 7.3 deg were used. Varying target to background and contrast conditions were used from 10% to 50%. Experienced military pilots were used as subjects. Results indicated significant differences in detection and recognition between static and dynamic conditions; however, the dynamic task was the harder as shown by greater subject variability. Effects of contrast were not as great with wide FOV as it was for the narrow FOV. The probability of acquisition increases with increasing contrast, regardless of FOV. Target acquisition times were best with a narrow FOV.

120. Jordan, S. Eye movement research program, Annual report. Naval Training Device Center Technical Report No. NAVTRADEVCEN IH-166, 1969.

In the first section of the report, the literature on technique and experimentation in eye movement research as it affects training device development is reviewed. In the second section, the current program of the Human Factors Lab is described. This includes the preliminary experimentation on visual guidance techniques and the refinement of the electro-oculographic method of recording eye position. The last section is devoted to a description of future programs.

121. Katz, M. S., Cirincione, P. A. and Metlay, W. Empty visual field studies: Some effects of corrective lenses, filters, and structure. Technical Report NAVTRADEVCEN IH-14, 1964.

An experiment was performed to explore target detection ability in a homogeneous visual environment as compared to that in a structured visual field. Twelve male college students were each given three experimental treatments in each visual field. These treatments were: (1) plano lenses (control), (2) corrective lenses (-0.5 diopter), and (3) filter lenses (neutral density 0.65). The task required the detection of targets subtending between 2'5" of visual angle and 6'8" of visual angle under conditions of positive contrast. Data analysis indicated significant differences between the empty visual field and the structured field, between the three experimental treatments, and between the six target sizes employed. Differences between subjects were also found to be significant. Target detection performance under conditions of the homogeneous visual environment as it relates to a pilot's task are discussed. The hypotheses of disorganization of systematic patterns of search and appropriate accommodation of the eye are also discussed.

122. Kerr, J. L. Visual resolution in the periphery. *Perception and Psychophysics*, 1971, 9, 375-378.

Visual acuity thresholds were determined for two Os with a 3 deg square target presented for 0.2 s with a steady illuminated surround field matched in luminance with the test field. Measurements were made in the fovea, and at 10, 20, and 30 deg along the horizontal meridian of the temporal retina, at luminances between -3.5 and 3.0 log mL. The foveal acuity luminance functions showed a large increase up to 1 or 2 log mL, but at peripheral locations very little increase occurred above 0 log mL. The maximum acuity reached at photopic luminances dropped sharply with increasing eccentricity. Visual acuities were two or four times higher than those previously reported for the periphery; methodological and target differences are presented to account for this result.

123. Kincaid, W. M. Theoretical models for the discriminatory process in visual detection. University of Michigan, Willon Run Laboratories, Report No. 2144-281-T, January 1959.

A variety of theoretical models for the discriminatory process involved in visual detection under laboratory conditions have previously been proposed, ranging from simple threshold notions to theories of signal detection in the presence of noise. These models may be shown to represent variants of a more general model, which is expressed in terms of an abstract space corresponding with the set of possible states of the central nervous system. Different subsets of this space correspond to different responses. Each stimulus presented generates a probability distribution of the space. This formulation clarifies certain issues and suggests possible avenues of future research.

124. Kirkpatrick, M. Development and evaluation of a random walk model of visual search behavior. North American Rockwell Corporation, Columbus, OH, Report No. NR68H-760, 2 December 1968.

A random walk model of visual search performance was proposed. The model views the search process as a Markov chain having two absorbing states, correct and incorrect acquisition. Equations for predicting acquisition probabilities and search time distributions in terms of the transition parameters were derived. The fit of the model to the existing search data was examined. The results suggested fairly close agreement between predictions and observations. It was concluded that data based on larger sample sizes would be required to adequately assess the validity of the model.

125. Kleinman, D. L., Ephrath, A. R., and Krishna Rao, P. Effects of target motion and image on AAA tracking. Air Force Office of Scientific Research Report, AFOSR-TR-78-0138, 1978.

The optimal control model of human response is applied to study target tracking performance of an AAA (Anti-Aircraft Artillery) system. The effects on tracking error of different motions, i.e., acceleration profiles, are studied via a covariance propagation modeling approach and via experiment. Different assumptions relative to the adaptive tracking behavior of the human are explored along with different schemes for inter-axis attention allocation. The effects of visual information inherent in a moving target image (e.g., size, aspect angle, etc.) are explored via comparison results with a moving image versus image of fixed size and shape. Experimental tracking results are compared with those predicted by the model.

126. Knowles, W. B. Flight controllers for jet transports. Human Factors, 1967, 9, 305-320.

Several designs for flight controllers for jet transports were developed to improve panel visibility and pilot comfort. The designs were rated by a panel of 12 pilot-evaluators. Three of the designs--Dual Side-Arm Yoke with Verier Handle, Circumferential Drive with a Vernier Handle--met with sufficiently high acceptance that their further development and evaluation appear warranted. The issues of gaining acceptance, of obtaining judgments from appropriate evaluators, and the need for further testing in dynamic flight simulators are discussed.

127. Koomen, M. J. Comments on air-to-air visibility at high altitude. National Research Laboratory Memorandum Report No. 343, 1954.

Aviators flying at high altitude report difficulty in sighting other aircraft. The factors causing this poor air-to-air visibility are discussed, particularly the phenomenon of "empty field" myopia. It is concluded that the correction of myopia may moderately improve air-to-air vision. An experiment for quantitatively determining the improvement is proposed, and some practical methods of correcting the empty field myopia are suggested.

128. Koomen, M., Scolnik, R. and Tousey, R. A study of night myopia. Journal of the Optical Society of America, 1951, 41, 80.

The phenomenon of night myopia, wherein the eye becomes relatively nearsighted in dim light, was investigated in detail using high contrast grating test objects. Night myopia first appeared at the brightness level where rod vision began to take place and grew larger as the brightness was further reduced. At the lowest brightness investigated, the myopia attained a value of 1.5 to 2.0 diopters, depending upon the observer. Night myopia appeared when accommodation was prevented by an optical method and also when accommodation was paralyzed with homatropine. It was therefore concluded that accommodation was not a significant cause of night myopia in the observers examined. The spherical aberration of the observers' eyes was measured and its effect upon the effective focal length of the eye was investigated with the aid of artificial pupils. Also studied were the properties of a simple glass lens having spherical aberration approximating that of the eye. All tests showed that night myopia, and its dependence upon the brightness level, is primarily a result of undercorrected spherical aberration of the eye. For some eyes, homatropine reduced night myopia slightly, but only to the extent that it reduced the spherical aberration. A review of the literature is included.

129. Koopman, B. O. Search and screening. Journal of the Optical Society of America, Part 1, June 1956; Part 2, October 1956; Part [illegible] October 19[illegible].

130. Koopman, B. O. The theory of search: I. Kinematic bases. Operations Research, June [illegible], [illegible].

The present paper is intended to provide the kinematic bases of visual search theory. It studies fairly simple cases of relative motion and draws inspiration from the kinetic theory of matter. In the conventional search situation, there are three general features: (1) The kinematic bases, involving the positions, geometrical configurations, and motions in the searchers and targets, with particular reference to the statistics of their contacts and the probabilities of their reaching various specified relative positions; [illegible] The probabilistic behavior of the instrument of detection (eye, radar, sonar, etc.) when [illegible]

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AIR-TO-AIR TARGET ACQUISITION: FACTORS AND MEANS OF IMPROVEMENT--ETC(U)
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the target; (3) The over-all result--the probability of contact under general stated conditions, along with the possibility of optimizing the results by improving the method of directing the search.

131. Koopman, B. O. The theory of search, II. Target detection. Operations Research, 1956, 4, 503.

The present paper discusses the inherent uncertainties in the act of detection under various specific conditions of contact. In the course of the discussion, a body of methods for applying probability to problems of detection is developed. It must be emphasized, however, that these methods are conditioned by the particular situation in the case of visual detection because the different elementary acts of looking or "glimpses" are essentially independent trials.

132. Kornfeld, G. H. and Lawson, W. R. Visual-perception models. Journal of the Optical Society of America, 1971, 61, 811.

Several theoretical models for the prediction of liminal contrast are studied. One model that employs the known excitation and inhibition spread functions of the eye accurately predicts, at 10 mL, thresholds for circular targets, sine waves, and rectangles, including the line as a special case. Semiempirically, this model is extended to include thresholds at low light levels.

133. Kraft, C. L. and Anderson, C. D. Prediction of target acquisition performance of aerial observers and photointerpreters with and without stereoscopic aids. Aerospace Medical Research Laboratory, AMRL-TR-73-36, 1973.

Forty-eight individuals were screened for their visual acuity, stereopsis, phorias, and color perception. After brief training, their target acquisition performance on a Sonne SC-2 display, of 1:3000 scale reconnaissance imagery in near-real-time, was measured. The effects of image chromaticity and display stereoscopy were investigated. Stereoscopic skill in the Sonne viewer was measured with achromatic and chromatic transparencies of regular and irregular terrain versions of the Critical Limens Stereo Test (CLST), displayed statically and dynamically. Stereoscopic performance was better with the achromatic tests over the chromatic tests, irregular background over the regular background tests, and stationary display over the dynamic display. All main effects were statistically significant. Observer performance correlated across all tests. Large individual differences in stereoscopic skill with chromatic and achromatic imagery were found. Chromostereopsis appeared to be a factor contributing to these differences and its measurement was necessary in maximizing predictions with chromatic imagery. Prediction of target acquisition performance on moving chromatic strip imagery displayed stereoscopically was good (r = 0.81) from scores on the chromatic/ regular/dynamic CLST. Target acquisition performance with achromatic imagery had a lower correlation with imagery displayed nonstereoscopically or stereoscopically resulted in similar target acquisition performance. The small difference in favor of chromatic imagery viewed stereoscopically was not statistically different from the other three combinations of main effects.

134. Krendel, E. S. and Wodinsky, J. Search in an unstructured visual field. Journal of the Optical Society of America, 1960, 50, 562-568.

Search in an unstructured visual field is an independent random process under the conditions described in this paper. The basic data for this report are 3072 search trials for each of four practiced observers. The four targets were circular and intercepted angles of 4.3', 13', 24', and 46'. Four search areas which measured 0.011, 0.084, 0.26, and 0.48 sterad, and four values of background luminance 0.01, 0.1, 1.0, and 12.4 ft-L were employed. Four contrasts were used for each of the 16 target size and background luminance conditions. These contrasts were generally at least twice the 95% threshold contrast. The data for the four subjects were combined, and since a one-parameter distribution was an adequate description, the mean time to detection has been tabulated for the 64 different experimental conditions to summarize these findings.

135. Kurke, M. I. Optical system design and the "empty field." Human Factors, 1959, 1, 72-74.

An experiment was performed to explore equipment design parameters for overcoming the accommodation disturbances in untextured visual fields which have been observed at high altitudes, and which have been rep· luced under laboratory conditions. Under controlled field conditions, however, the phenomenon could not be elicited.

136. Lamar, E. S. Operational background and physical considerations relative to visual search problems. Proceedings of Symposium. Washington: National Academy of Sciences/National Research Council Publication 712, April 1959, pp. 1-9.

In order to make the most of the eyeball as a search device, it is necessary to consider its various attributes in the operational setting in which it is to be used. This I shall try to do in the remainder of my talk . . . The work on which this presentation is based was done for the Navy in what is now the Operations Evaluations Group (OEG) in the Office of the Chief of Naval Operations . . . in spite of the rapid advances in electronics, the human eye still constitutes an important instrument for primary search. Electronic equipments using visual displays are not competitors of the human eye, but aids to extend its range beyond that set by physiological limitations.

137. Lamar, E. S., Hecht, S., Shlaer, S., and Hendley, C. D. Size, shape, and contrast in detection of targets by daylight, I. Data and analytical description. Journal of the Optical Society of America, 1947, 37, 531-545.

The influence of size and symmetry has been studied on the contrast required for the recognition of rectangular targets against background brightness of 2950 and 17.5 foot-Lamberts. Targets less than 2 minutes in diameter require the addition of a contrast total light flux to the background. Larger targets require less contrast but more total flux as the area increases, until beyond 200 square minutes when the required contrast becomes independent of area. For areas below 100 square minutes, square targets are most efficient for their area; the greater the ratio of length to width the greater the contrast required. All the measurements can be unified on the supposition that the visually critical region of a target is a ribbon just inside its perimeter and about 1 minute wide. Evidently, contrast is not judged over the area of the target, but across the boundary.

138. Lamar, E. S., Hecht, S., Hendley, C. D., and Shlaer, S. Size, shape, and contrast in detection of targets by daylight vision, II. Frequency of seeing and the quantum theory of cone vision. Journal of the Optical Society of America, 1948, 38, 741-755.

Frequency-of-seeing curves have been obtained for targets having various image perimeters at background brightnesses of 2950 and 17.5 foot-Lamberts, respectively. A description of the data has been obtained on the basis of the assumption that the absorption of a light quantum by a foveal cone is a random event which is subject to the laws of chance. On this basis, the data indicate that the detection of a target takes place across the image boundary; that in order to detect the target, at least one of the cones along the boundary must absorb at least 4 quanta, and that this critical number of quanta is the same for each of the two background brightnesses investigated. At the higher brightnesses, this critical number of quanta absorbed from the target is about equal to the random fluctuation to be expected in the number absorbed from the background during the critical time of one exposure.

139. Langmuir, I. and Westendorp, W. F. A study of light signals in aviation and navigation. Physics, November 1931, 1, 273-317.

Visibility of Point Sources: Laboratory experiments have been devised to make the visibility of light signals under conditions essentially similar to those encountered by the aviator or navigator. Data have been collected on the direct visibility of flashing point sources of light of different colors, flash lengths and intervals, against different backgrounds; the time it takes to locate a visible beacon was studied as a function of the beacon intensity and the frequency of flashing. The threshold candle power C required for visibility of a point source at distance D (cm) against a background of brightness H (candles x cm^{-2}) is given by the empirical equation $C/D^2 = 3.5 \times 10^9$ H&.u1/2. Colored point sources were not found to be useful except in the case of red lights with background intensities above moonlight. For an airplane approaching a beacon it is advantageous to use frequencies of flashing lights as high as 12 to 30 per minute, although with exceptionally clear atmosphere, lower frequencies may be better.

Visibility of Diffuse Light: In a study of the visibility of flashes of diffuse light superimposed on a steady white background, white light flashes gave the best results. The sensitivity of light from point sources is from 10,000 to 170,000 times as great as from diffuse sources, this range corresponding to an increase in background brightness from 0.1 starlight up to moonlight. A selective differential photoelectric receiver is described which detects signals of moderated diffuse light of an intensity of only 4×10^{-11} candles x cm^{-2}. This sensitivity is independent of the steady background brightness up to 100 times moonlight, and is from 6 to 13,000 times as great as that of the range of background intensity from darkness to moonlight.

Diffusion of Light in Fog: The greatest difficulty in transmission of light signals through fog lies in the loss of advantages of point sources. Dense fog may increase the distances at which light signals may be detected. The range depends to a considerable extent on the reflectivity of the ground. A theoretical treatment of the diffusion of light through fog, based on the scattering of the light rays by fog particles, indicates that airplanes can be guided through fog at distances of several miles by means of diffuse modulated light acting on a differential photoelectric receiver.

140. LaPorte, H. R and Calhoun, R. L. Clue utilization in target recognition: A methodological study. Autonetics, Division of North American Rockwell, Report No. T6-2258/501, September 1966.

A study was conducted to test a method for establishing and analyzing target/ background clues used in target recognition. The method was used to determine (1) whether the clues used by observers in target recognition can be meaningfully classified, (2) whether the clue categories are related to target recognition performance, and (3) whether performance is related to target codability. Codability was defined as the readiness with which elements of the environment can be stored in memory and verbally described by the observer. While viewing motion pictures of flights over target areas, subjects attempted to identify preselected targets. The film was stopped periodically and subjects were asked to designate the target, to indicate their confidence in the designation, and to describe the most important clues leading to the designation. Subjects' clue descriptions were categorized and compared with their recognition performance scores to determine whether a significant relationship existed between clue types and performance. The relationships among confidence level, target codability, and performance were also examined. The most significant finding of the study was that, for most targets, non-target clues were more important to successful target recognition than were target clues. The results also confirmed earlier observations that observers usually recognize targets correctly before their confidence in their judgments reaches a maximum. Target recognition was found to be a positive function of the effectiveness with which the observer can encode the visual world, i.e., target codability is a factor in target recognition performance. The method was found to be useful for studying the perceptual and cognitive processes of observers in a dynamic target recognition task. Modifications are suggested to improve the usefulness of the method. Further research problems stemming from the results of the present study are proposed.

141. Lauria, S. M. and Strauss, M. S. Eye-movements during search for coded and uncoded targets. Naval Submarine Research Lab, Groton, CT, Report No. 787, June 1974. (AD-A002-713)

Eye-movements and search times of four subjects were studied as they searched for a target-dial in a 4 x 4 array of dials which were differentiated either by (1) color, (2) shape, (3) a combination of color and shape, or (4) were uncoded. Search time varied reliably between conditions; it was generally shortest in the color condition, followed by color-shape, shape, and the uncoded condition. Subjects were capable of using shape and color simultaneously. There was no difference in ratios of increase of search time for color and shape as the target was situated more peripherally, and there was evidence that shapes, if properly chosen, might be as effective a coding device as color. Search time was strongly associated with the average number of fixations required for target detection but not with other measures of eye-movements. Subjects did not exhibit a reliable or characteristics scanpath, and methods of scanning did not relate to search-time.

142. LeCocq, A. D. Impact of human factors on an airborne night vision system. Paper presented at the Human Factors Society Fourteenth Annual Meeting, San Francisco, CA. 13-16 October 1970.

This paper describes the impact of human factors in an airborne night vision system. The overall human factors effort included design support, laboratory studies, training, and operator performance measurements during system flight tests. Before completing the first system, a human factors tracking simulator was developed and used in a tracking study to obtain optimum control-stick loop gain. A target acuity simulator was also developed to simulate the viewer imagery and chromaticity in order to obtain measures of the operators' minimum perceptible acuity. Statistically significant correlations were obtained between laboratory and flight performance data; therefore, the human factors tracking and target acuity simulators are predictors of operator performance and can be used for screening potential operators as well as for training in the laboratory to reduce training costs. The impact of human factors on this system resulted in effective and efficient operator performance, design of applied research equipment, and a body of data on operator performance.

143. Leibowitz, H. L. Detection of peripheral stimuli under psychological and physiological stress. Visual Search, Symposium conducted at the spring meeting 1970, Committee on Vision, Division of Behavioral Sciences, National Research Council, National Academy of Sciences, Washington, D. C.

To summarize the results of these experiments, it is suggested that a distinction between the functional and physiological visual fields is significant in evaluating the performance of the organism in any situation involving peripherally presented information. A large number of conditions that do not exist in the normal laboratory environment may diminish the ability to process peripherally presented information. However, this diminution can, to some extent, be eliminated by training. The generality of these relations is, of course, limited to the range of conditions used in the previously described experiments. Although we have pushed cardiovascular stress as far as one can reasonably hope, we have not introduced variables such as perceptual-motor load or emotional stress over very wide ranges. Whether it is possible to maintain peripheral discrimination in an extreme degree of various kinds of stress, or combinations thereof, is a question that can only be answered by experiment. Certainly, the data for the marathon driving experments suggest that peripheral discrimination is

impaired in severe vigilance tasks. In any event, the data so far indicate clearly that the contribution of the peripheral visual field is variable and must be considered in order to understand the functional performance of the visual system.

144. Leibowitz, H. W., Myers, N. A., and Grant, D. A. Radial localization of a single stimulus as a function of luminance and duration of exposure. Journal of the Optical Society of America, 1955, 45, 76.

Accuracy of localization of the radial position of a single stimulus was determined for various luminance-exposure duration combinations. Localization accuracy, provided the stimulus is seen, is independent of luminance and duration, but varies with the radial position of the stimulus. The results are discussed in terms of events critical to the localization accuracy and it is concluded that the magnitude of photochemical events in the end organs does not limit localization accuracy for supraliminal stimuli.

145. Levine, S. H. and Youngling, E. W. Real-time target acquisition with moving and stabilized image displays. Office of Naval Research, Target Acquisition Symposium, Naval Training Center, Orlando, FL, 14-16 November 1972, 165-176.

Current high-performance aircraft achieve speeds which exceed man's ability to visually acquire a target before it is overflown. We are faced with the problem of extending man's capability to match that of the aircraft. Electronic sensors such as radar and TV systems offer potential solutions; however, considerable research into the best utilization of these systems is still required. McDonnell Aircraft's approach to this research has been to design and build a variable configuration display mockup (VCDM) in which actual flight images can be electro-optically manipulated to measure performance and evaluate system improvements. To maintain our operational orientation, stimulus imagery was generated using aerial imagery from the McDonnell Douglas Reconnaissance Laboratory data base, containing strategic and tactical targets.

146. Low, F. N. Peripheral visual acuity. Ophthalmological Review, 1951, 45, 80-99.

Peripheral visual acuity has been the subject of speculation since ancient times and in the last 100 years has been measured quantitatively by numerous investigators. The purpose of this paper is to survey the present status of knowledge in this field. A short historical sketch is followed by the presentation of quantitative data. Consideration is given to the factors known to affect various measurements and to the probable significance of each. Peripheral visual functions, such as color vision, motion perception, light and dark adaptation and sensory studies, are omitted except when they have definite bearing on acuity problems. The measurements and method associated with the study of central acuity are used for comparison.

147. Ludvigh, E. and Miller, J. W. Some effects of training on dynamic visual acuity. U.S. Naval School of Aviation Medicine Joint Project No. NM-001-075.01.06, September 1954.

An investigation has been made of the effects of training on the dynamic visual acuity of 200 Naval Aviation Cadets. It was found that the effect of training was substantial at a high angular velocity of test object, regardless of whether improvement is expressed in absolute or percentage terms. At 110 deg/sec the amount of improvement in dynamic visual acuity with training, the "ultimate" threshold, and the rate of improvement were all found to vary greatly among individuals. The thresholds of the 20 subjects having the highest thresholds were compared with the 20 subjects having the lowest threshold values. A significant difference was found to exist at trial one and similarly at all trials thereafter.

148. Ludvigh, E. and Miller, J. W. Study of visual acuity during the ocular pursuit of moving test objects, I. Introduction. Journal of the Optical Society of America, 1958, 48, 799.

Visual acuity may be measured during the voluntary ocular pursuit of moving tests objects. This visual function has been referred to as dynamic visual acuity. The apparent movement of the test object is produced by rotating a mirror in the desired plane of pursuit by means of a wheel and disk type variable speed drive. The range of angular velocities utilized is 10 degrees per sec to 170 degrees per sec at the nodal point of the tested eye. It is shown that visual acuity deteriorates markedly and significantly as the angular velocity of the test object is increased. It is shown further that the relationship between visual acuity and the angular velocity of the test object may be described satisfactorily by the semiempirical equation $Y = a + bx^3$. It is also pointed out that individuals possessing similar static acuity may differ significantly in their dynamic acuity. The possible causes for the observed deterioration of acuity are discussed and it is concluded the imperfect pursuit movements of the eye result in a continued motion of the image on the retina. This motion results in a reduced intensity contrast, which is a factor in producing loss in acuity.

149. Luria, S. M., Ferris, S. H., McKay, C. L., Kinney, J. A. S., and Paulson, H. M. Vision through various scuba facemasks. Human Factors, 1974, 16, 395-405.

The visual performance using five commercially available facemasks was compared. Measurements were made of visual fields, visual acuity, stereoacuity, hand-eye coordination, accuracy of distance estimates, and accuracy of size estimates at both near and far distances. In addition, the optical properties of the masks were measured and the susceptibility of each mask to fogging was tested. Some masks were superior for one purpose and inferior for another purpose. For example, the mask which had lenses designed to compensate for the optical distortions found under water improved size and distance estimates and hand-eye coordination, but degraded acuity and stereoacuity. The results were not explained on the basis of differential susceptibility to fogging.

150. Lyman, B. Visual detection, identification, and localization: An annotated bibliography. Human Resources Research Office Technical Report No. 68-2, 1961.

This literature survey was undertaken to explore information on the nature of and conditions for effective visual perception at low light levels. From the survey, 407 reports or studies were selected for inclusion in the annotated bibliography. With a few exceptions, the material falls within the areas of detection, identification, and localization. Many laboratory studies are included which could undergo appropriate modification for repetition in natural settings at low light levels.

In each annotation, the purpose and the results or conclusions of the study are stated; method and procedure are indicated only briefly.

151. Macchiaroli, C. R. A review of the literature on the theory of visual target detection probabilities. Naval Postgraduate School, Monterey, CA, Master's thesis, September 1973. (AD 769-745)

Information on visual target detection is widely scattered in the literature. This thesis presents a review and a categorization of models in the field of visual target detection. A literature research matrix is presented to aid the researcher in locating existing models which meet his requirements.

152. McCluskey, M. R., Wright, A. D., and Frederickson, E. W. Studies of training ground observers to estimate range to aerial targets. Human Resources Research Office TR 68-5, May 1961.

This report describes a series of studies dealing with methods for training observers in range estimation performance. This research is part of a continuing effort to improve individual training and performance in aerial target detection. Six experiments were conducted. The specific purposes of the research were to determine the effects of training on performance, identify some of the factors that influence range estimation, and determine the effectiveness of miniaturizing the training environment. Several variations of range estimation training methods were used, but the basis for all techniques was either immediate knowledge of results after making an estimation, "paired associate" presentation of aircraft position with true slant range, or the use of an occluding object as a range estimation aid. The research data were obtained by field testing at Fort Bliss, Texas.

153. McColgin, F. H. Movement thresholds in peripheral vision. _Journal of the Optical Society of America_, 1960, _50_, 774.

The absolute velocity thresholds of movement were determined at 48 positions in peripheral vision. An aircraft-type instrument, with a standard altimeter hand, was located at random positions on the concave, black surface of an 80 in Fiberglass hemisphere. Four types of movement were investigated

(clockwise and counter-clockwise rotation, vertical and horizontal motion) under conditions of constant photopic lighting. While the subject fixated on the center point of the hemisphere, the absolute velocity threshold of each type of movement was determined for each position using the method of limits. Ten airline pilots served as subjects. The absolute threshold isograms on perimetric charts for both rotary and linear motion are elliptical in shape, with the horizontal axis approximately twice as long as the vertical axis. There is no difference between a subject's ability to see clockwise or counter-clockwise rotation. An individual's ability to perceive vertical motion is slightly better than his ability to perceive horizontal motion near the horizontal axis. Velocity and area swept by the instrument hand are significant factors in the perception of movement, but they are not similarly correlated for all types of movement.

154. McCormick, E. J. Human factors in engineering and design. New York: McGraw-Hill Book Company, 1976.

155. Mangulis, V. and Graham, W. The effectiveness of the see-and-avoid doctrine: Safe vertical clearance from clouds. Federal Aviation Administration, Final Report No. FAA-RD-71-115.

The collision hazards of allowing VFR aircraft to fly in the proximity of clouds are evaluated and compared with the number of near-misses or collisions expected on a clear day due to human failure to see and avoid other aircraft. Some numerical results are presented for representative air traffic.

156. Matthews, M. L., Angus, R. G., and Pearce, D. G. Effectiveness of accommodative aids in reducing empty field myopia in visual search. Human Factors, 1978, 20, 733.

When a visual detection task is performed with distant targets in the absence of adequate accommodative cues, a performance loss is obtained which has been attributed to empty field myopia. It is shown that in a visual search situation, an accommodative aid located at optical infinity improves detection by approximately 30% over empty field performance. It is further demonstrated that such an aid may overcome the conflicting accommodative cues provided by proximal contours defining the search area, i.e., a situation that is analogous to the detection of distant targets by observers searching through aircraft cabin windows.

157. Middleton, W. E. K. Vision through the atmosphere. Toronto: University of Toronto Press, 1952.

158. Miller, J. W. Study of visual acuity during the ocular pursuit of moving test objects. II. Effects of direction of movement, relative movement, and illumination. Journal of the Optical Society of America, 1958, 48, 803.

It was demonstrated that the manner in which visual acuity deteriorates as the angular velocity of the test object increases is similar regardless of whether the motion is produced by moving the target vertically, horizontally, or by rotating the observer in a horizontal plane. It was shown also that the semiempirical equation, $Y = a + bx^3$, describes satisfactorily these three types of movement. It was pointed out that individuals having a low acuity threshold in the vertical plane of movement will be likely also to have a low threshold in the horizontal plane. It was shown that although 5 to 10 footcandles may be sufficient illumination when the test object is stationary, visual acuity is substantially benefited by increases up to 125 footcandles when the observer is rotated. This corroborates earlier findings repoted by Ludvigh.

159. Miller, J. W. and Hall, R. J. The problem of motion perception and orientation in the Ganzfeld. Visual Problems of the Armed Forces. Ed. by M. A. Whitcomb. Washington: National Academy of Sciences, National Research Council, 1962.

It may be said that although the eye may lack a reliable ocular proprioceptive mechanism, as suggested by some workers, the individual seems to possess a surprisingly accurate spatial orientation sense in the absence of retinal cues. Subjects appear to be able to detect fairly small displacements, and, in addition, to perceive motion directly in the Ganzfeld, whether it be illuminated or darkened. Further experimentation is being planned for the purpose of determining some of the parameters utilized by the subject under such conditions.

160. Miller, J. W. and Ludvigh, E. An analysis of certain factors involved in the learning process of dynamic visual acuity for 1000 Naval Aviation Cadets. US Naval School of Aviation Medicine, Pensacola, FL, Technical Report, April 1957.

The purpose of the present study was to examine certain aspects of the learning process of dynamic visual acuity for a group of 1000 subjects. The assumption was made that the rate of reduction of the acuity threshold with increasing practice is proportional to the difference between the present and "ultimate" threshold. The target velocities employed were 20 deg/sec and 110 deg/sec and the illumination used was 40 footcandles. Comparisons were made between the total 1000 subjects, the 100 best and the 100 poorest terminal performances.

161. Miller, J. W. and Ludvigh, E. Visual detection in a uniformly luminous field. Journal of Aviation Medicine, 1958, 29, 603.

A new technique has been devised whereby subjects are presented with a totally homogeneous visual field in which either stationary or moving targets may be employed. Provision has been made to move these targets over a wide range of angular velocities. Target acquisition time has been investigated as a function of both size and location of target. Early results indicate that observers are uncertain as to the presence or absence of targets even though they may be substantially above threshold in size. It has been found that targets exceeding the threshold by as much as a factor of 10 to 15 times can disappear while being fixated by an observer in a homogeneous field. We believe that this phenomenon cannot be accounted for by fluctuations in the accommodative mechanisms of the eye, and that other factors, as yet unexplored, must be involved.

162. Miller, J. W. and Ludvigh, E. J. Time required for detection of stationary and moving objects as a function of size in homogeneous and partially structured visual fields. Joint project of the Kresge Eye Institute, Detroit, MI, under Contract No. NR-568(00), Office of Naval Research, Project Designation No. NR-142-023; and U.S. Naval School of Aviation Medicine, Bureau of Medicine and Surgery, Project NM 17-01-99, Subtask 2, Report No. 15. Also in NAS-NRC Publ. 712, 1960.

The purpose of the experiments described in this paper was to determine the time necessary for detecting spherical targets of various sizes in homogeneous and partially structured visual fields. It was found that as size of test objects increased, the likelihood of detecting it in a given interval of time increased. It was shown that although the measured acuity threshold was 3 minutes of an arc, a substantial period of time was needed (20 s) to locate test objects as much as six times this size. It was pointed out that because of the lack of position sense in the eye, the subject has no way of knowing where he is looking, with the result that search is carried out in a grossly inefficient manner. It was also shown that structuring the field to the extent of adding two vertical black lines did not alter the acquisition time significantly. The assumption is made that visual search is carried out in such a manner as to utilize discrete search acts. There is thus a probability that the test object will be found in a given search act, and if the search were conducted systematically, the target could be found simply by exhausting the regions of the field one by one. It is demonstrated, however, that an hypothesis incorporating the assumption of a systematic search does not satisfy the experimental data.

163. Miller, J. W. and Ludvigh, E. The perception of apparent movement in the Ganzfeld. Journal of the Optical Society of America, 1961, 51, 57.

The apparent persistence of seen movement in a homogeneous visual field (Ganzfeld) is described. The task required that the subject observe the movement of a single, black, spherical stimulus in an otherwise empty field and to report when its movement ceased. The time interval between real and apparent cessation of motion was defined as "time delay." The hypothesis advanced states that the apparent speed of the stimulus in the Ganzfeld is dependent upon the square of its real velocity, its duration and its size. This may be expressed as $t = r + (1/av^2)$ where t = time delay, r = reaction time, v = velocity, and a = the constant of inverse proportionality. The data are discussed in terms of "constant velocity." The notion here is that a stimulus traveling at high speed and for a relatively long duration produces a more definite perception of velocity than one traveling slowly and observed for a shorter period of time. Therefore, when the former stimulus suddenly is stopped, the resulting contrast of velocity is great and the response to it rapid, whereas when the latter stimulus similarly is stopped, the resulting contrast of velocity is slight and its perception therefore slower. The data were shown to support this hypothesis.

164. Miller, J. W. and Ludvigh, E. The effect of relative motion on visual acuity. Survey of Ophthalmology, 1962, 7, 83-116.

This article deals with the effect on foveal visual acuity of relative motion between the test object and the observer. Curiously enough, this subject appears to have been investigated first only in 1947. However, a special case of visual acuity when the object is moving, namely, the size threshold or minimum visible, the ability to perceive the mere presence of an object but not its details, was discussed as early as 1937. The classical method of testing visual acuity with the observer and the test object both stationary is, of course, almost ideal for the determination of refractive errors, but the eyes are seldom employed under those circumstances. An exception is the remarkable task of reading, during which task most individuals exhibit fixation pauses interspersed with saccadic movements. On the other hand, the eyes are frequently employed while the individual is himself walking, riding on or in some vehicle, or viewing a moving person or object. The questions which arise concerning visual acuity when relative motion exists between the eye and the test object are numerous. This article reviews and interprets the experimental results obtained in an effort to answer some of these questions.

165. Millhollon, A., Lyons, J., and Graham, W. Air-to-air visual detection data. I. Summary of air-to-air visual detection data; II. Summary of visual detection data; III. Summary of visual detection data taken from the ATA/CAS flight tests. Federal Aviation Administration Interim Report FAA-RD-73-40, April 1973.

Since the pilot is required to visually detect potentially hazardous intruders in the Pilot Warning Instrument (PWI) concept, the question of pilot air-to-air visual detection is critical. The significant conclusion from the data presented in this report is that under good Visual Flight Rule (VFR) conditions, if the pilot is given accurate information on the location of intruding aircraft, he has a high likelihood of seeing the intruder in sufficient time to take any required evasive action. This report presents two Control Data Corporation (CDC) papers summarizing data from two different air-to-air visual detection activities.

166. Mocharnuk, J. B. Visual target acquisition and ocular scanning performance. Human Factors, 1978, 20, 611.

The present research investigated the effects of information and physical variables on visual search performance and on the ocular activity associated with that performance. Three experiments were completed using a brief exposure technique. The manipulated variables included memory load, exposure duration, and the physical grouping of information within a display. Several patterns emerged from the data. Stimulus information appeared to have no effect on eye movement measures. Instead, the physical restrictions imposed on the search task were responsible for changes in ocular behavior. However, there was a substantial effect of information on total search performance. The per item search rate increased as the total information in the display increased. This information effect was interpreted in terms of a variable processing rate hypothesis.

167. Monk, T. H. Sequential effects in visual search. Acta Psychologica, 1974, 38, 315.

Two types of repetition effect were demonstrated in a visual search situation. A target dot of one of four possible brightnesses was randomly placed in a field of non-target dots. A target repetition effect caused search time to be significantly reduced if the trial had a target dot of the same brightness as was used in the immediately preceding trial. An "edge effect" caused targets in the outer part of the display to have longer search times than those in the inner part. A spatial sequential effect caused targets appearing in the inner part to reduce search times if the target in the immediately preceding trial also had appeared in the inner part. Possible implications and mechanisms of the sequential effects are discussed.

168. Monk, T. H. Target uncertainty in applied visual search. Human Factors, 1976, 18, 607.

Target uncertainty was studied in an applied typ· of task with non-alphanumeric material and no fixed order of scanning. Targets varied from non-targets along a single dimension. Target uncertainty was found to produce a 9.5% increase in search time and did not interact with either target difficulty or target position.

169. Monk, T. H. Sequential expectancy in visual search. Human Factors, 1977, 19, 601.

An experiment was designed to determine whether there was a sequential expectancy effect in visual search by which subjects carried over an expectation of the duration of the search from one trial to the next and produced a shorter search time on the nth trial if the n-1 trial had had a search time of similar magnitude. Search time was controlled by the surreptitious insertion of lags between the onset of the background (i.e., start of the search) and the actual appearance of the target. Post-target search time (total search time minus lag) was then used as the dependent variable. Three lags (0, 7.5, and 15 sec) were used in a random order. Two effects emerged. Post-target search time was found to be reduced if the previous trial had used the same lag as the present trial, and post-target search time was found to increase with lag. Both effects were explained by the construction of a sequential expectancy model.

170. Morris, A. and Horne, E. P., eds. Visual search techniques, Proceedings of a Symposium sponsored by the Armed Forces-NRC Committee on Vision, April, 1959. Publication 712, National Academcy of Sciences-National Research Council, Washington, D. C.

171. National Transportation Safety Board. Aircraft accident report: North Central Airlines, Inc., Allison Convair 340/440 (CV-580), N90858, and Air Wisconsin, Inc., DHC-6, N4043B near Appleton, WI, 29 June 1972. National Transportation Safety Board Report No. NTSB-AAR-73-9, April 1973.

A North Central Airlines Allison Convair 340/440 (CV-580) and an Air Wis⌐onsin DHC-6, collided over Lake Winnebago near Appleton, WI, at approximately 1037 c.d.t., 29 June 1972. The two passengers and three crewmembers aboard the CV-580 and the six passengers and two crewmembers aboard the DHC-6 were fatally injured. Both aircraft were destroyed as a result of the in-flight collision and the subsequent water impact. Both aircraft were proceeding in accordance with visual flight rules and were within minutes of landing at their respective destinations. Visual meteorological conditions existed at the time and place of the accident. The NTSB determined that the probable cause of this accident was the failure of both flight crews to detect visually the other aircraft in sufficient time to initiate evasive action. The Board is unable to determine why each crew failed to see and avoid the other aircraft; however, the Board believes that the ability of both crews to detect the other aircraft in time to avoid a collision was reduced because of atmospheric conditions and human visual limitations.

172. Neisser, U. Visual search. Scientific American, June 1964, 210, 94.

The achievements of clipping readers suggest that our own basic finding is no artifact: the speed of a search is independent of the number of different targets that can terminate it successfully. This conclusion applies equally to the simple search for particular letters and to the more difficult, slower search for particular kinds of words. In all likelihood, it applies to other searches also. The rate at which one scans a crowd for a familiar face probably does not depend on the number of people with whom one is familiar. In a simple task such as the search for any one of 10 letters, these results are fully compatible with the concept of a multilevel perceptual system. They suggest, moreover, that a number of operations at a given level are carried out simultaneously. We do not yet understand the search for specific classes of words well enough to make a model of the process involved. It is already clear, however, that the cognitive operations involved add up to something more than simply a search for component letters and something less than a full appreciation of the meaning of each word encountered.

173. Noton, D. and Stark, L. Eye movements and visual perception. Scientific American, 1971, 224, 35-43.

Recordings of the points inspected in the scanning of a picture and of the path the eyes follow in the inspection provide clues to the process whereby the brain perceives and recognizes objects.

174. Overby, L. T. The application of adaptive training techniques to visual search. Unpublished Ph.D. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1973.

175. Overington, Ian. Modelling of random human visual search performance based on the physical properties of the eye. Air-to-Ground Target Acquisition. AGARD Conference Proceedings No. 100, June 1972, Brussels, Belgium.

The physical properties of the eye lens and retina together with the involuntary eye movements (tremor and drift) are considered as basic factors defining single glimpse detection probability. Coupling of data with these simple probability theories of information transmission from eye to brain via neural networks allows accurate predictions of several sets of basic laboratory threshold data. Introduction of the concept of convolution of object profiles with the spread function of the eye lens allows extension of such single glimpse predictions to unsharp objects. The effects of atmospheric attenuation and range dependency of subtended size may also be introduced at this stage. Using this comprehensive formula for single glimpse probability as an input, a cumulative search probability model is developed for random search which takes account of search field of view, visual lobe effects, and the transition from single glimpse to multiple glimpse situation at any part of the field of view.

176. Parkes, M. R. Visual and televisual detection studies. I. The effect of navigational uncertainty and target difficulty on detection performance. Department of Ergonomics and Cybernetics, Loughborough University of Technology Technical Report, April 1967.

A static simulation technique was used in this target detection experiment to investigate the effect of navigational uncertainty, range to target, and target difficulty on four measures of performance. These were detection probability, search time, confidence level of decision, and map-briefing time. The experiment was based on a 7 x 7 (targets x conditions) Latin Square design. Seven skilled pilots and navigators, and 21 students of comparable ability, as assessed by intelligence and personality test, acted as subjects. The results showed that the performance measures considered were not

affected by navigational uncertainty. For the unskilled subjects detection probability and search time were significantly related to range. As range increased from one to four miles, detection probability increased linearly and search time increased linearly. There were significant differences between targets for each measure of performance. When the targets were ranked according to each of these measures, significant associations were found between the rankings. Targets which had high detection probabilities tended to have short search times and high confidence levels associated with them. Conversely, targets which had low detection probabilities tended to be those associated with long search time and low confidence levels. The performance of skilled subjects was very similar to that of the unskilled subjects, but the former took significantly less time in map-briefing and in searching for the targets. In the discussion sections, the general suitability of the experimental technique is assessed and the results considered in relation to further work at present in progress.

177. Parkes, K. R. The effect of limited search time on target detection performance. Department of Ergonomics and Cybernetics, Loughborough University of Technology Technical Report, March 1969.

This report describes the fifth in a series of experiments intended to investigate performance at a statistically simulated target detection task. The main aim of this experiment was to obtain detection performance data under paced conditions in which search time, i.e., the time the subject was allowed to view the photographic display, was limited to (a) 10 seconds, and (b) 5 seconds. Twenty-one unskilled subjects were assigned to each of these conditions, in a replicated Latin Square experimental design. In a subsidiary experiment, a limited amount of data was obtained relating to search times of 1 second and 2.5 seconds, seven subjects being assigned to each of these conditions. The data obtained under these paced conditions were compared with those obtained previously under unpaced conditions, in which subjects were allowed to decide for themselves when to respond. The recorded search times ranged from 1.2-55.6 seconds. The main results obtained from the analysis of these data were: (1) Overall detection probability decreased consistently as search time was reduced; the highest value was that obtained under unpaced conditions, more marked for the small targets than for the large targets; (2)

the overall detection probabilities achieved in each of the paced search times were higher than the cumulated probabilities achieved in the corresponding times under unpaced conditions; (3) Both detection probability and mean confidence level were significantly related to range (1-4 miles), but in each case there was no significant interaction between range and search time.

178. *The Perception and Application of Flashing Lights. An International Symposium held at Imperial College.* London: Adam Hilger, Ltd., 1971.

179. Petersen, H. E. and Dugas, D. J. The relative importance of contrast and motion in visual target detection. RAND Corporation Report No. R-688-PR, March 1971. (AD-722-407)

This study investigates a fundamental question concerning the visual process-- the relative importance of contrast and motion in the detection of moving targets--that arose during a previous experiment by the authors in visual detection of moving targets. The results of this study may be used for further modification of an exponential detection model developed by H. H. Bailey of the RAND Corporation, allowing it to be applied to targets having variable speed and contrast. It will have military application in problems of camouflage, reconnaissance, and remote displays, with particular relevance to problems of airborne search for both low-flying aircraft and moving surface vehicles.

180. Post, R. B., Owens, R. L., Owens, D. A., and Leibowitz, H. W. Correction of empty-field myopia on the basis of the dark-focus of accommodation. *Journal of the Optical Society of America*, 1979, *69*, 89.

The influence of negative spherical corrections on the detection of small increment flash presented in a uniform field or Ganzfeld were determined. The range investigated included each observer's normal correction as well as values based on the focus assumed by each observer in total darkness (dark-focus of accommodation). A correction equivalent to the dark-focus resulted in maximum sensitivity. The results suggest a convenient technique for the determination of optimal correction for empty-field viewing conditions.

181. Powell, E. Smoking and its effects upon visual accommodation. Research Quarterly, 1938, 9, 30-36.

The apparatus in this series of studies consisted essentially of a means of recording the instant of recognition of a near letter and a far letter in alternation, changing the letter after each recognition, and recording the time cumulatively over a sequence of near-far and far-near transits of accommodation. The subjects were either confirmed smokers or those who smoked very occasionally. With regard to recognition of the near letter, which might involve ciliary tetanus, it was found that smoking had a depressor effect--the speed was decreased rather than increased as with the far letter. It seems reasonable to explain the relatively slower speed of near recognition time after smoking on the grounds that smoking increases the unsteadiness of the highly tetanized ciliary muscle. The speed of near-far accommodation was increased by smoking in spite of delayed recognition. From the whole series of experiments it can be concluded that smoking first stimulates and then depresses the function of visual accommodation, and that the effects of rest and smoking upon visual acuity, accommodations, recognition time, and enunciation time can be readily and objectively measured.

182. Prescott, R. Visual aids in acquisition. Ballistic Systems Division, Air Force Systems Command, Norton AFB, CA. Report No. BSD-TR-66-252.

The problem of visual aids in acquisition is examined in some detail. The capabilities of the naked eye aided by monoculars or by image intensifiers are examined. It is proposed that a 20 deg field-of-view image converter instrument be fabricated based on a design developed in this study and that a second instrument be built with a field-of-view determined by our experience with preacquisition pointing aids in TRAP-6. A possible design for a 5 deg field-of-view is proposed. It is also proposed that an acquisition simulator be built for training and for the evaluation of instrumentation being developed.

183. Radio Corporation of America, Burlington, MA. Target detection and recognition study, final report. U.S. Naval Ordnance Laboratories, Corona, CA, Report No. CF-588-90, September, 1962.

The experiment described herein has determined the quantitative effects on the ability to localize a terrain sector with respect to a photograph of a larger terrain area of (1) television line coverage of the given sectors, (2) signal-to-noise ratios of the image, (3) use of spot wobble scanning, and (4) level of complexity or "information density" of the actual terrain under consideration. The results have shown that the time to localize a sector is essentially constant when sectors of approximately 0.6 to 1.0 mile on a side are scanned by 1000- to 250-lines per frame. Performance was significantly poorer when the same sectors were scanned only by 125 lines. Video noise degrades performance systematically at all line coverages. Localization is performed least easily when the signal-to-noise ratio is 18 db, and improves consistently as the ratio increases from 15 to 19 to 27 db. Performance with images derived from a spot-wobble scan mode was not significantly different from performance with images derived from linear scanning. Terrain sector localization was faster and more accurate when the information density of the actual terrain was sparse rather than moderately or highly complex. No significant interactions were found among the experimental variables. It is concluded that the terrain localization task involved in navigational correction control can be performed as well with a 250-line television system at increased noise levels as one giving more refined definition.

184. Randall, H. G., Brown, D. J., and Sloan, L. L. Peripheral visual acuity. Archives of Ophthalmology, 1966, 75, 500.

185. Randle, R. J. Volitional control of visual accommodation. Advisory Group for Aerospace Research and Development. Paper #2157 reprinted from Conference Proceedings No. 82 on Adaptation and Acclimatization in Aerospace Medicine.

Whether or not humans can exercise voluntary control over their state of accommodation has been a matter of conjecture and a research topic that has received only cursory attention. The present study reports on an attempt to show that volitional control is possible in most individuals when feedback is provided which indicates to the subject his present accommodation level. The feedback was provided by modulating an audiooscillator with the output of a servo-controlled, infrared optometer which continuously monitored the refractive state of the subject's eye. The subject thus heard a tone that varied in frequency as a function of his refractive state. Six young, male college students with normal vision were "trained" to control their accommodation first using the tone and then without it. A specific task they learned was to accommodate toward 0 diopters (optical infinity) when a 3 diopter checkerboard was extinguished and they viewed a dark, empty field. The performance of the trained subjects was compared to that of six untrained subjects on 2 dark empty field test tasks. The tasks were: (1) to maintain infinity focus while viewing a dark empty field for 3 minutes, and (2) to go to infinity focus from a 3-diopter target when it was extinguished and a dark empty field ensued 3 times during a 3 minute period. A statistical analysis of the results showed that the trained group made significant reduction in their dark field myopia under these conditions, but the untrained subjects did not.

186. Reading, V. M. The effect of target movement on visual search. <u>NATO Symposium on Image Evaluation</u>, 1969.

187. Reilly, R. E. and Teichner, W. H. Effects of shape and degree of structure of the visual field on target detection and location. <u>Journal of the Optical Society of America</u>, 1962, <u>52</u>.

The effects of the degree of structuring and the form of the visual field on target detection and target location were investigated for three different search times. Thirty undergraduate subjects searched for low visibility targets on a screen and recorded the target locations on prepared data sheets. The results suggest that both target detection and location are related in a nonmonotonic fashion to the degree of structure and to the form of the field. The structuring continuum was defined as the division of the search area into two or more partitions of equal area. Optima for both measures occurred at the low end of the continuum. Of the two forms investigated, performance with square fields was generally superior to that for circular fields. In answer to a questionnaire after the experiment, a majority of the subjects reported a preference for searching the square fields. Both target detection and target location varied directly with the search times. However, the functions tended to increase rapidly at first and then level off at the longer search time.

188. Robinson, J. E., Cook, K. G., and Zeleny, C. E. Pilot judgments of simulated collisions and near misses: A comparison of performance with uncoded and two-tone coded models. Journal of Applied Psychology, 1961, 45, 359.

An F-100 flight simulator and an F-151 aerial gunnery trainer with a black-and-white, closed circuit television system were used to present standardized visual flight problems involving a variety of relative course situations and altitude changes, resulting sometimes in "collisions" and sometimes in one of a variety of "near-collisions." Six experienced pilots completed a total of 144 training and practice problems and 288 test problems. Objective records taken during each problem permitted quantitative measurement of the accuracy and speed with which the pilots were able to identify the outcome as "collision" or "miss." Four target images, all generated from miniature B-47 models, were presented in counterbalanced test session order and in random sequences of problems. One model was painted all white, the other three were treated with dark and light paint to identify pairs of the cardinal aspects of any aircraft: top versus bottom, front versus back, and left versus right. The objective of the investigation was to determine whether or not these visual codings would improve the pilot's ability to judge the outcomes of the simulated flight situations. Statistical analysis was accomplished in terms of descriptive values for accuracy and speed, and of inferences drawn from analysis of variance. No statistically significant differences relevant to the objectives of the study were obtained between the two-tone coded models and the all-white uncoded model. The investigators believe that it is appropriate to conclude that visual coding of the type studied is not of significant aid to a pilot in visually determining the existence of a collision threat or a safe passage; and, that pilots rely on perception of relative motion more than any other factor in judging the probability of colliding with another aircraft.

189. Rowland, G. E. and Silver, C. A. Aircraft exterior lighting and marking. Federal Aviation Administration Report No. FAA-RD-72-24, May 1972.

This study investigates the contemporary state of human factors knowledge concerning exterior lighting and marking. Efforts to increase conspicuity or impart information through resort to exterior marking or painting are now and, in the absence of an unforeseen technological breakthrough, will probably continue to be essentially useless. A simple white-on-top, black-on-bottom paint scheme, which leaves about one-fourth of a metal aircraft bright aluminum to cause specular reflection of sunshine, is recommended as the most likely overall compromise paint design. An attempt to define standardized exterior lighting system failed because sufficient hard data does not exist to compare system components. Large-scale field research to compare all components of all major systems is urgently required. This research would compare red versus white beacons, beacons plus running lights versus either alone, and all other major combinations. Research is outlined for study of backscatter and daylight lighting. In addition, eight experiments are described which would investigate innovative new ideas in coding concepts which may have applicability. Collectively, the research program outlines a very advanced, very large-scale exterior lighting research program for the FAA to conduct at NAFEC. It is concluded that a contemporary standard lighting system is feasible at present and should be adopted on the basis of a massive field trial. At the same time, an imaginative exploratory research program is urgently needed.

190. Ryan, L. C., Gerathewohl, S. J., Mohler, S. R. and Booze, C. F. To see or not to see: Visual acuity of pilots involved in midair collisions. Federal Aviation Administration, OAM Report FAA-AM-75-5, 1975.

The medical records of airmen involved in midair collisions from 1970 through 1973 were reviewed and compared with two other groups of pilots: (1) pilots involved in other types of accidents, and (2) pilots without any accident records. There is nothing in the results to indicate that the pilots with visual corrections are a greater risk.

191. Savage, R. Field independence and field dependence: A review of the literature. Virginia Polytechnic Institute and State University, Unpublished paper, 1978.

FI-FD could be related to a particular type of training which could be useful information for any training program involving pursuit tracking such as piloting and driving. Therefore, the perceptual style of FI-FD could be useful for prediction, selection, and training.

192. Schiffler, R. J. Eye movement technique to measure visual search behavior. Society for Information Display, 7th National Symposium on Information Display, Technical Session Proceedings, Boston, MA, October 1966.

One of the missions of the Display Techniques Branch at Rome Air Development Center is to identify variables which influence visual search behavior, investigate their interactions, and specify standards which should be used in designing and evaluating large scale display systems. In the Information Techniques Section of the Display Techniques Branch, this research has been two-pronged. First, "in-house" and contractual efforts primarily in the area of psychophysical studies (color specifications, coding, TV resolution) and, secondly, display criterion development. This latter has as its purpose the development of a metric to evaluate the information transfer potentially of large scale display designs. In the area of visual search, the Information Techniques Section has recently turned its attention to the development of an eye movement device which would aid in evaluating the influences of various display parameters and be an additional diagnostic tool in the criterion development field. This paper presents the approach used in developing this device and a more detailed explanation of possible uses of the apparatus.

193. Self, H. C. Performance measures, observer selection, and reconnaissance/strike systems effectiveness. Target Acquisition Symposium, Office of Naval Research, Naval Training Center, Orlando, FL, 14-16 November 1972.

Various measures of observer performance at the task of finding and recognizing targets are discussed, along with considerations of the type of behavior required to do well on each measure. It is shown that to do well by different criteria requires different observer behavior. Experimental data are given which compare observers on different performance measures to illustrate the problem of selecting the most proficient observers. Conclusions are drawn about observer selection and its impact upon reconnaissance/strike systems effectiveness.

194. Senders, J. W. Visual scanning behavior. Visual Search, Symposium conducted at the Spring Meeting, 1970, Committee on Vision, National Research Council, National Academy of Sciences. Washington: 1973.

A program involving extensive instrumentation of a simulator and of the pilots who operate it was undertaken and completed. The investigation has involved the recording and subsequent transformation of many varieties of data relating to both system and human performance. The basic goals were the testing of models and the examination of the ways in which human operators and systems dynamics interact in a more or less deterministic way. Validation in the simulator is limited to two different models of where people look and why they look there when flying an aircraft through a variety of routine maneuvers. One of these models is basically a sampling theorem application; the other is an extension of cyclic queue with the addition of certain cost factors guiding the sampling behavior. The results indicate that the statistical predictors are weaker than the queueing model, which depends heavily on individual pilot's estimates of the cost of making certain control activities and the cost of exceeding certain limits.

195. Short, E. A. U.S. Naval Postgradute School, Monterey, CA, Master's Thesis, 1961.

When two aircraft are physically oriented so that continuation on their individual flight plans will result in collision, the final decision of the pilots to take avoiding action is most often based upon visual detection of the other aircraft. Considerable laboratory experimentation has been conducted and reported on the various aspects of visual detection, as has much been written about the general theory of computing visual detection probabilities. This thesis is concerned with correlation of a portion of these laboratory results with detection theory into an analytical model for the computation of range at which an aircraft will be detected with a given probability for a stated set of meteorological conditions. The theoretical model is first developed for the case of a lookout or observer riding in the aircraft with no other duties to perform than visual searching. Consideration is then given to the case of the pilot who must distribute his available time between visual searching and in-cockpit operation of his aircraft.

196. Silverthorn, D. G. The "K" factor in air-to-ground acquisition modeling. Air-to-Ground Target Acquisition., AGARD Conference Proceedings No. 100, June 1972, Brussels, Belgium.

The simplest acquisition task from the modeling viewpoint is that of detection under conditions in which the target and its location are fully learned. This task is scored as a "potential detection range." The starting point for modeling this task is the Tiffany Data (Blackwell, 1946) which provides the probability of detection at a given target contrast as a function of angular size and field brightness. The link to detection range is provided by appropriate size-range and contrast-range functions. This paper illustrates that correspondence obtained between the shapes of the probability-range curves is good both for field and simulated field data, but that actual performance levels are much lower than predicted. A degradation factor (the "K" factor of the title) has been introduced to cover differences between simulated and direct field trial data. The paper examines the factors on which K is dependent and describes relevant experiments at BAC and the associated attempts at modeling them. It is at once a progress statement and an indication of the necessary further studies.

197. Sloan, L. L. Area and luminance of test object as variables in examination of the visual field by projection perimetry. Vision Research, 1961, 1, 121.

A modified Goldmann perimeter is used which provides means of measuring, in any desired location in the field, the luminance of the projected test object which is just perceptibly brighter than a background of fixed luminance. Data for normal eyes is presented to show the relationship between area and threshold luminance and the variation in this relation from center to periphery of the retina. Similar tests of eyes having defects in the visual field provide a measure of the extent and density of the defect and a direct test for abnormality in the capacity for areal summation.

198. Smith, S. W. Visual search time and peripheral discriminability. Journal of the Optical Society of America, 1961, 51, 1462 (abstract only).

Ten complex abstract visual displays consisting of 256 circular pseudotargets (clutter elements) and one target (a regular polygon) were selected from a previous study to produce a large range of search times (time taken by observer to find the target). These displays differed in the degree of similarity (shape, size, and contrast) between target and pseudotargets. When these search time data were compared with the results of an investigation of the discriminability of the ten target-pseudotarget combinations for peripheral viewing, a large negative correlation was obtained. Target-pseudotarget combinations which produced long search times had to be fixated almost directly to be differentiated, whereas combinations which produced short search times could be differentiated out to 26 deg from fixations.

199. Smith, S. W. Time required for target detection in complex abstract visual display. Report of Project MICHIGAN 2900-235-R, 1961.

The purpose of this study was to determine the effects on search time (t) of two display variables: (1) the number of objects present in the display (N), and (2) the similarity between the object sought (target) and nontarget objects (pseudotargets). Projected displays consisting of discrete, sharply defined, randomly distributed objects were presented to a group of four observers. The objects were considerably brighter than the field. All pseudotargets in a display were identical. The equation, $\log t = m \log N \pm n$, where m and n are slope and intercept constants, respectively, expresses the data quite well for N values between 1 and 1024. The target used in this part of the investigation was a square, and the pseudotargets were circles of the same contrast and size (area) as the target. The effects of differences between target and pseudotarget in terms of size and contrast were investigated by using a 4 x 4 (size x contrast) factorial design. As contrast difference between targets and pseudotargets increased, search time decreased. Size differences had a similar but somewhat greater effect on search time. In every case where the target and pseudotargets differed in both size and contrast, median search time was shorter than when either difference was used alone. In the third part of this study the pseudotargets were circles of the same contrast and size as the targets. The targets used were regular polygons: triangle, square, pentagon, and hexagon. Search time increased regularly as the number of sides of the target increased.

200. Snyder, H. L. Modulation transfer function area as a measure of image quality. Visual Search, Symposium conducted at the Spring Meeting, 1970, Committee on Vision, National Research Council, National Academy of Sciences. Washington: 1973.

Many of the problems in operational use of imaging or viewing systems have been attributed to the gross incompatibility between the quality (and often the quantity) of imagery produced and the capabilities and limitations of the observer. In order to reduce the number of relationships between performance of the interpreter and image quality, several studies have attempted to find a summary measure of image quality, one to which several design variables may be reduced. The strong promise of the MTFA measure, as demonstrated by Borough et al., coupled with the applicability of MTFA to electronic and electrooptical imaging systems of a wide variety, led Boeing to collect the information extraction performance data required to complete this work (Borough). This paper reports the results of that study. The modulation transfer function (MTF) simply defines the percent original contrast that is transmitted by a system as a function of the spatial "closeness" of two elements in the original object plane. The MTFA is the area bounded by the system MTF curve, some arbitrary low-frequency cut-off (if used), and the detection threshold curve for the combination of the human observer and the imaging system. Thus, the system MTF is rigorously defined in the absence of noise, whereas the detection threshold curve includes all display, environment, and visual capability factors. One of the advantages of MTFA is that it lends itself to analytical prediction at an early stage in the design of any imaging system. Further, it is easily verified in the laboratory when the detection-threshold curve is known.

201. Snyder, H. L. Dynamic visual search patterns. Visual Search, Symposium conducted at the Spring Meeting, 1970, Committee on Vision, Division of Behavioral Sciences, National Research Council, National Academy of Sciences. Washington: 1973.

The data obtained in this study, although exploratory in nature, permit the following conclusions: (1) The search process is largely cognitive and involves detailed visual pattern-matching only as a final verification of target identity. (2) The characteristics of the surrounding terrain and its associated cultural features are at least as important as the characteristics of the target itself. (3) Superior target acquisition performance is associated with shorter dwell-times. (4) The search behavior exhibited here is inadequate for detecting off-flight path targets due to restricted angular area in which fixations occurred. (5) With regard to development of a mathematical model of visual search, the following implications should be noted; first, fixation durations of 0.3 to 0.4 s are approximately invariant with target type, target range, and likelihood of acquisition; second, the probability that a fixation will fall on any particular portion of the image is highly dependent on the resemblance of that portion to the expected appearance of the target or target cues; third, the probability of looking at a target falls off rapidly as the target departs from the ground track or velocity vector of the aircraft. (6) Training techniques that reduce dwell-times are likely to increase the range of target acquisition; some operational ad.antages might be obtained for the military in this manner.

202. Snyder, H. L. and Greening, C. P. The effect of direction and velocity of relative motion upon dynamic visual acuity. Autonetics, Division of North American Aviation Report, January 1965.

In this study, human dynamic visual acuity was related to relative stimulus velocity when the stimulus motion contained a vector of motion toward the observer. The specific parameters investigated, and their effects upon visual acuity, were: (1) Direction of Stimulus Motion Across the Retina.--Lower acuity thresholds were obtained in the horizontal plane (0 deg) of motion than in the vertical plane (90 deg). Proportional increases in 30 and 60 deg planes were found. (2) Angular Velocity of the Stimulus Perpendicular to the Line of Sight.--As the velocity increases from zero to two radians per second, the visual acuity threshold increases exponentially from 1.00 to over 3.00 minutes of arc. This rate of increase is greater as the plane of motion changes from horizontal to vertical. (3) Rate of Approach of the Stimulus Directly Toward the

Observer.--The visual acuity threshold increases as the rate of approach increases from zero to 4.5 ft per second. (4) Exposure Time of the Stimulus.--Lower thresholds were obtained with a 6/60 s exposure time than with either 2/60 or 4/60. The latter two did not differ significantly. (5) Stimulus Pattern.--Lower, more reliable thresholds were obtained with the Snellen E than with either the Landolt C or the Bausch & Lomb checkerboard. The results were discussed in terms of their appplication to object recognition from automobiles and low-altitude, high-speed aircraft.

203. Stone, Lawrence D. Theory of optimal search. New York: Academic Press, 1975.

This book deals with the problem of optimal allocation of effort to detect a target. A Bayesian approach is taken in which it is assumed that there is a prior distribution for the target's location which is known to the searcher as well as a function which relates the conditional probability of detecting a target, given it is located at a point (or in a cell) to the effort applied there. The allocation problems considered are all one-sided in the sense that only the searcher chooses how to allocate effort. For example, the target is allowed to move but not to evade. Thus, pursuit and evasion problems are not considered. The primary focus of the book is on problems in which the target is stationary. For this case, we use a generalized Lagrange multiplier technique. This method is also extended to find optimal plans in some cases involving false and moving targets. For the case of Markovian target motion, results are, for the most part, presented without proof. The following basic classes of search problems are considered: search for a stationary target, search in the presence of false targets, optimal search and stop, and search for targets with conditionally deterministic motion and Markovian motion.

204. Tanner, W. P. and Swets, J. A. A decision-making theory of visual detection. Psychological Review, 1954, 61, 401.

This paper is concerned with the human observer's behavior in detecting light signals in a uniform light background. Detection of these signals depends on information transmitted to cortical centers by way of the visual pathways. An analysis is made of the form of this information, and the types of decisions which can be made, based on the information on this form. Based on this analysis, the expected form of data collected in "yes-no" and "forced choice" psychophysical experiments is defined, and experiments demonstrating the internal consistency of the theory are presented.

205. Taylor, J. H. Contrast thresholds as a function of retinal position and target size for the light-adjusted eye. Visual Problems of the Armed Forces. Ed. by M. A. Whitcomb. Washington: National Academy of Sciences, National Research Council, 1962.

Binocular visual thresholds for circular targets of positive contrast and several angular sizes have been measured at various positions in the binocular visual field. A relatively high (75 foot-Lamberts) adapting luminance was used, and the target duration was always 0.33 s, chosen as typical of the dwell-time used in visual search. Four young, highly practiced emmetropic male observers were used as subjects for the experiment. Data collection proceeded by the conventional "yes-no" method of constant stimuli. Approximately 80,000 observations were made, and the resultant frequency-of-seeing curves were fitted by Gaussian integrals, by use of a variation of the probit analysis technique adapted for computer treatment. The experimental findings differ, as anticipated, from other data, e.g., Blackwell and Moldauer (1958), which relate only to the case of very brief target flashes, or to long target durations. These differences involve not only changes in the values of threshold contrast, but also an alteration of the shape of the curves relating threhold contrast to position in the visual field.

206. Taylor, J. H. Practice effects in the performance of a simple visual discrimination task by initially naive observers. University of California, Scripps Institute of Oceanography Reference 62-21, October 1962.

An experiment was conducted to evaluate the effects of early practice during training in a simple visual discrimination task. Four experimentally naive subjects completed a series of 50 experimental sessions, and their data, based upon threshold estimates reduced from 50,000 observations, were examined for both short-term and long-term practice effects. Short-term effects were found to be limited to very early sessions, with essential stability of sensitivity having been reached by the fifth session. This result is consonant with other studies of training effects in the visual domain. Long-term effects, up to the fiftieth session at least, were not found. It was concluded that naive observers may confidently be assumed to have attained a stable level of performance after very few training sessions in tasks requiring a single discrimination.

207. Taylor, J. H. Use of visual performance data in visibility prediction. Applied Optics, 1964, 3, 562-568.

This paper is concerned with certain visual performance data which are now available, with the techniques used in applying these data to visibility problems, and with one or two examples in which it has recently been verified that these techniques lead to useful predictions. Some of the most useful visual performance data are presented, and then the manner of interrelating them is shown; some considerations in making the jump from laboratory to real life are listed, and, finally, a specific problem and its mode of solution is described.

208. Taylor, J. H. Practice effects in a single visual detection task. Nature, 1964, 201, 691.

The results of this work indicate that short-term practice effects--presumably caused by habituation to the experimental environment and familiarization with the response mode--in simple visual detection are followed by long-term and gradual further reduction in measured threshold. Because of the moderate slope of the second limb of the curve, and the presence of appreciable session-to-session variability, it is understandable that long-term effects of this sort have remained undetected in investigations limited to a small number of experimental sessions.

209. Taylor, J. H. Factors underlying visual search performance. Presented at NATO Symposium of Image Evaluation, Munich, Germany, 1969.

Visual search may be regarded as a special case of image evaluation. In this case, the image may be a primary one in real object space and time or it may be derived from some secondary or intermediate imagery or display in real time or with time either compressed or expanded or, as in the case of a photograhic display, frozen. Before image evaluation can occur, it is necessary that the object be detected, that is, it must be sufficiently different from the background in which it is embedded so that the observer becomes aware of its presence. The needed difference between object and background may be based upon luminance contrast, color contrast, size, shape, texture, movement, and temporal characteristics.

210. ten Doesschate, G. Vision in an empty field. Ophthalmologica, 1960, 140, 322.

Under conditions prevailing in the experiments, some young persons (not all), when looking at an empty visual field, accommodated in a slight degree between 0.25 and 1.75 diopters. Three aged subjects did not accommodate under these conditions. Some young subjects showed the same amount of accommodation when the whole visual field was empty (more than 180 deg) and when the extension of the field was only 20 deg. In some cases, the same amount of accommodation was found with illuminations of 1.2 and 500 lux. The window frame, used in Method D, did not seem to produce any accommodation stimulus; neither did the presence of the imitation of an illuminated dashboard. When the empty field is viewed through colored glasses, the perception of chroma gradually diminishes and is often followed by a sensation of dark gray. In two cases, there were observed periods of apparent darkness.

211. Thomas, F. H. Low altitude aerial observation: An experimental course of instruction. Human Resources Research Office Technical Report 80, October 1962.

The research objective was the development of training methods and techniques that would improve the ability of the aerial observer to detect, identify, and locate military targets during low altitude flight. Potential training areas identified from an analysis of data on the flight performance of aerial observers in a tactically realistic field test are visual search, speed of recognition, geographical orientation, and target location. In a series of five field experiments, methods and techniques developed for training in the four skill areas were administered to officer personnel from the combat arms who had had no previous experience as aerial observers. Results showed that with training in visual search and specific recognition, the students' in-flight identification improved 40%. A similar gain was recorded for the students' performance in in-flight target location after they had had training in target location. After students had had training in both geographical orientation and target location, the addition of training in geographical location improved performance by another 10%. However, the students' mean error for in-flight target location exceeded 200 meters from the target center. Student performance was compared with that of experienced aerial observers. The students received 18 hours of experimental instruction and 3 hours of practice flight, combined with 11 hours of conventional instruction--a total of 32 hours. The majority of the experienced observers had received the minimal training as required by AR 95-51, which included 78 hours of classroom instruction and 20 hours of practical flight, and they had a median of 19 hours of flight experience. On a combat-simulated test, the students in the experimental groups matched the experienced observers on detection, identification, and location of targets. All three groups combined detected a mean of 57% of the 27 target groups contained in the test. Of the separate major items located within a target complex, 64% were detected, and of those detected, 87% were correctly identified. In target location, the mean error of the combined groups from target center was 400 meters. On the basis of the results of the studies, it is concluded that the training methods and techniques developed provide more efficient means for training in the basic skills of low altitude observation than do currently available methods.

212. Thomas, F. H. and Caro, T. H. Training research on low altitude visual aerial observation: A description of five field experiments. Task OBSERVE Research Memorandum 8, U.S. Army Aviation Human Research Unit, U.S. Continental Army Command, Fort Rucker, AL, 1962.

This memorandum reports five field experiments conducted by the U.S. Army Aviation Human Research Unit, under Task OBSERVE. This task was initiated in late 1957 in response to a request from the Department of the Army and the United States Continental Army Command to conduct an aerial observation training. The purpose of the task is to develop improved methods for training human air observers. Four basic skill areas which underlied aerial observation performance were identified: visual search, speed of target recognition, geographical orientation, and target location. The five field experiments of this task are summarized in another Technical Report. This research memorandum provides a detailed description of these experiments. Experiment 1 compares the effectiveness of four visual search methods. Experiments 2 and 3 relate classroom speed of recognition training to in-flight observation performance. Experiment 4 is concerned with improving the ability of the aerial observer to remain geographically oriented while in flight. Experiment 5 is directed toward improving the accuracy with which the airborne observer can locate the position of ground targets on his map. Participation in these experiments was limited to the military group most likely to receive the prescribed training. Accordingly, the population sampled consisted of young officers from the three combat arms (infantry, armor, artillery) who had no previous aerial observation experience. The available pool at each military installation visited (consisting of 30 to 42 officers) was administered a pre-experimental test to determine the initial proficiency for that activity to be measured by post-experimental testing. On the basis of initial scores, subjects were assigned to experimental groups of matched distribution.

213. Thornton, C. L, Barrett, G. V., and Davis, J. A. Field dependence and target identification. Human Factors, 1968, 10, 493.

Target identification has usually been studied with respect to environmental parameters which affect the performance of the "human operator." Rather than use this method, which treats individual differences as sources of error, the investigators studied individual differences and related them to Witkin's concept of perceptual style. Witkin and his associates were able to differentiate subjects on their ability to pull a visual item from an embedded context. Two experiments were conducted using the Embedded Figures Test (EFT) as a measure of perceptual style. Significant correlations between perceptual styles and the ability to correctly identify targets in aerial photographs were found. Since a great deal of research has been conducted in the area of perceptual style, it is possible to utilize this research in connection with problems associated with target identification. Implications in the areas of experimental design, selection, and training were discussed.

214. Townsend, C. and Mace, J. Sighting range of targets against the night horizon sky. Report R67ELS-24, March 1967.

A series of graphs have been prepared giving the sighting range of targets viewed against the horizon sky at night versus horizon sky luminance. A range of target sizes, target-to-background contrasts, and meteorological ranges are considered for the case of 95% detection probability.

215. Van Cott, H. P. and Kinkade, R. G. (Eds.) Human engineering guide to equipment design. New York: McGraw-Hill Book Co., 1973.

216. Vicory, A. C. A brief history of aircraft identification training. Human Resources Research Office, George Washington University, Professional Paper 27-68, August 1968.

This paper presents a selective review of previous and contemporary methods of teaching aircraft recognition to personnel manning forward area air defense weapons. Methods in use since about 1940, including the WEFT System (image-analysis concept), the Renshaw System (whole-image concept), the modified WEFT-Renshaw System (learning of aircraft features), and a HumRRO method are examined. HumRRO research designed to coordinate studies of training with generalization, retention, and transfer in order to provide a better assessment of training effectiveness is described.

217. Volkmann, F. C. Vision during voluntary saccadic eye movements. Journal of the Optical Society of America, 1962, 52, 571-578.

Vision seems to be a continuous process even though eye movements occupy a portion of the time spent in reading or inspecting objects in the field of view. This observation has led to the supposition that a "blanking out" of vision occurs with saccadic eye movements. Some workers attribute this effect to the rapid motion of the image on the retina. Others have suggested a central inhibition, possibly related to the physiological mechanisms of attention.

The present research compared vision during saccades with vision during fixation by means of three representative psychophysical tasks. Each stimulus pattern was presented to the fovea in the form of an instantaneous flash that was delivered before, during, or after an eye movement. The flash lasted only 20 µsec, so that retinal blur due to movement was reduced to a negligible amount. The time of the stimulus flash was signaled on a continuously moving film on which the eye movements were recorded by a corneal reflection technique. Detection thresholds for dot patterns and recognition thresholds for words were found to be about 0.5 log units higher during saccades than during steady fixation. Similar differences, though smaller and less consistent, were found for the minimum angles for the resolution of gratings. It is concluded that vision is not "blanked out" during eye movements, but that it is significantly depressed even under conditions that minimize blur due to movement of the retinal image, and that assure foveal stimulation.

218. Volkmann, F. G., Schick, A. M., and Riggs, L. A. Time course of visual inhibition during voluntary saccades. Journal of the Optical Society of America, 1968, 58, 562.

Partial inhibition of vision occurs during voluntary saccadic eye movements. This paper reports its time course, measured by detection of a target flashed at various times in relation to the saccade. One value of stimulus luminance was chosen which was nearly always detected by the fixating eye, but hardly ever by the moving eye. A dot pattern was presented to the fovea in 6 ms flashes of this luminance under photopic viewing conditions. Photographic records of each saccade made by the subject and each stimulus flash permitted analysis of the precise time of occurrence of the flash in relation to the saccade. Under these conditions, curves from three subjects showed that detection decreases to 50% for a flash occurring about 20 ms before the onset of the saccade and reaches a minimum such that vision of the flash is almost completely absent when it occurs during the saccade. Detection then begins to improve, reaching the 50% point again for a flash occurring about 75 ms after the onset of the eye movement. Results are compared with other studies which employed different viewing conditions, and the use of the data to support a notion of partial central inhibition is evaluated.

219. Vos, J. J., Lazet, A. and Bouman, M. A. Visual contrast thresholds in practical problems. Journal of the Optical Society of America, 1956, 46, 1065-1068.

Contrast thresholds measured with dots and Landolt rings are given as a function of object size and brightness for 31 observers. The desirability of presenting upper and lower threshold curves is pointed out. Differences with the experiments of Blackwell are discussed. The influence of training (in threshold determination) is shown to be negligible.

220. Walker, J. T. Lythgoe's visual stereophenomenon in the natural environment: A possible factor in air and highway accidents. Human Factors, 1974, 16, 134-138.

The path of a horizontally moving object, when viewed binocularly, appears distorted if a light shines in only one of the observer's eyes. The image in the lighted eye has a shorter visual latency period than the image in the other eye, and this temporal difference between image latencies translates into an apparent spatial difference between image positions-- binocular disparity--which results in the apparent depth displacement of the moving object. In the natural visual environment, one eye can be lighted by the sun while the other is shaded by the nose, and, thus, distortions may be produced in the apparent paths of air lanes, or of traffic moving on the ground. The roles that such distortions may play in some air and highway accidents have not been considered previously.

221. Weber, O. Statistical and flight dynamic studies on conflict detection and resolution in civil aviation. Royal Aircraft Establishment, Library Translation 1903, May 1977.

The report deals with theoretical studies in the field of statistics and flight mechanics concerning conflict detection and resolution by the "see and avoid" concept. American and German statistics on mid-air and near mid-air collisions are discussed. For flights without acceleration, basic geometrical and physical aspects of conflict detection are derived and details given on the angles of vision from the pilot to the other aircraft and on "blind spots." Horizontal evasive maneuvers are analyzed in detail and their effectiveness is presented in many graphs which can be used for numerous tasks. Two observation error models are described and their influences on the distances estimated where horizontal evasive maneuvers are possible. Vertical maneuvers are treated concisely and some tentative suggestions for the improvement of flight safety are made.

222. Weissman, S. and Freeburne, C. M. Relationship between static and dynamic visual acuity. Journal of Experimental Psychology, 1965, 70, 141.

Research in the area of dynamic visual acuity (DVA) has pointed out a controversy as to the nature of the relationship between DVA and static acuity. This study tried to answer the following questions: (1) Is there a relationship between static acuity and DVA at any speed? (2) If there are relationships at different speeds, are they different kinds of relationships? Thirty women, college students, were given 6-speed (20, 60, 90, 120, and 180/s) and 1 static measure of acuity. Thresholds for the first 4 speeds were found to show a significant linear relationship with the static acuity thresholds. The relationship disappeared at the 2 highest speed thresholds.

223. Westheimer, G. Eye movement responses to a horizontally moving visual stimulus. AMA Archives of Opthalmology, 1956, 932-941.

A number of eye movement responses to moving visual stimuli have been recorded photographically under conditions in which it is reasonable to expect the exclusion of factors involving the higher perceptual levels, as well as of the lower reflex arcs. The inference is drawn that these responses give information concerning the mode of operation of what are often called the psycho-optical reflexes. It appears that two basic response patterns are utilized: saccadic movements and constant velocity following movements. The latter are initiated by a movement in the visual field or the perception of movement. In the original response to a moving stimulus, both types of eye movements appear, and they are changed discretely and at intervals as the differences between the target direction and eye position develop. When the target position is changed instantaneously from one position to another, the response consists only of saccadic movements. All responses lag behind the stimulus by an interval of the order of a reaction time. As the subject becomes familiar with the target motion, he/she is able to anticipate the latter. The reacted time then becomes elimination, and gradual accelerations of the eye movements become apparent which do not otherwise seem to form part of the basic response pattern.

224. Whitcomb, M. A. and Benson, W. (Eds.) Vision research: Flying and space travel. Proceedings of the Spring meeting, NRC Committee on Vision, 1964.

The papers presented at this meeting concerned visual problems related to low altitude, high-speed flying, space travel, and incapacitating effects on pilots resulting from inadvertent viewing of nuclear detonation.

225. White, W. J. and Monty, R. A. Vision and unusual gravitational forces. Visual Capabilities in the Space Environment. Ed. by C. A. Baker. New York: Pergamon Press, 1965, 65.

This report reviews and evaluates the research and observations pertaining to the effects upon human vision of unusual gravitational forces, which will be encountered in space flight operations. Increased g and null gravity are the major topics of discussion. Within each topic, the gross and qualitative changes in vision are discussed first. Quantitative and analytical studies are next reviewed, ranging from the application of threshold methods of psychophysics to the performance of flying tasks such as dial reading. Operational experience of the astronauts is included. Techniques for ameliorating the undesirable effects of acceleration and null gravity are summarized.

226. Whiteside, T. S. C. Accommodation of the human eye in a bright and empty visual field. J. Physiol., 1952, 118, 65.

An investigation is being carried out to determine whether, in the presence of a bright field of vision in which there is no detail to fixate, accommodation can be relaxed voluntarily to infinity. The method consists of employing a test object which is so small as to be visible only when it is near the point at which the eye is focused. This test object consists of a glass plate on which is a regular pattern of black spots, each of which subtends 1/2-1' of arc. The test is observed through a +4D lens, by means of which, when the spots are out of focus and therefore invisible, the subject is presented with an empty field, the brightness of which is 180 foot-Lamberts. The subject views the empty field binocularly, although recognition of the test object is monocular. The experimental procedure consists of telling the subject to "look in the distance" whilst the test object is slowly brought toward him. The test object is always suddenly and clearly recognized, although the direction from which it comes is unchanged and familiar to the subject. The results are calibrated by placing a fixation spot at predetermined distances and noting at which point the test objects become visible. Ten subjects were examined, and it was found that, although an attempt was being made to relax accommodation to infinity, a mean of 1.7D was being exerted within 10 s of looking at a point 12-18" away. Progressive relaxation took place until after about 45 s a mean of 1.16D was reached. Beyond this, there was little improvement in relaxation. The majority of the subjects were slightly hypermetropic, the mean value of the far points being -0.06 D (standard deviation 0.619). The problem appears to have some bearing to the findings of Campbell and Primrose (1952) that under scotopic conditions there was a failure to relax accommodation to infinity.

227. Whiteside, T. C. D. <u>The problems of vision in flight at high altitudes</u>. London: Butterworth Scientific Publications, 1957.

"Flight at high altitude" refers in general to flight in the stratosphere or in the upper limits of the troposphere. It does not refer to a specific height above sea level, but it always means flight above cloud. In practice, the altitude at which observations were made was generally about 40,000 feet, but the findings can also be applied to flight outside the earth's atmosphere. "The problems of vision" dealt with are those which give rise to immediate difficulty in seeing. Whilst some are common to lower altitudes, most of the problems investigated appear at present to be peculiar to high altitude. With one exception, the problems dealt with do not arise from speed and so the craft in which these problems arise may be either balloon, civil transport, or high performance fighter. The problems investigated affect only those whose duties require them to look out on the high altitude scene.

problems investigated affect only those whose duties require them to look out on the high altitude scene.

228. Whiteside, T. D. C. Visual perception of movement. Flying Personnel Research Committee, FPRC/Memo 191. Lecture given at the Royal College of Surgeons of England, Edridge Green Lecture, August 1963.

The controversial question of the visual perception of motion, which has been for so long attracting biologists, and which indeed formed the basis of the school of Gestalt psychologists, is of interest to the clinician whose patient reports false movement of the visual field, to the psychologist who seeks to explain abberations of perception, and to the biologist concerned with the applications of research to the problems involving the control of vehicles, either terrestrial, airborne, or even astronautic. Although the question has frequently been the subject of discussion, the time is maybe ripe to reconsider possible mechanisms, particularly in the light of recent experimental work and neurophysiological concepts. The term "visual perception of movement" will be employed to refer to movement which an observer sees as taking place relative to himself. The visual information that such movement is taking place can be obtained in three ways. It can come first through changes in the retinal image, for example, as it glides over the retinal mosaic; or it can come through changes in position of the eye, or again it may occur as an aftereffect of either of these stimuli. This being so, it may make for ease of handling of the subject if it is considered under two main headings: first, movement _in_ the visual field; secondly, movement _of_ the visual field. If this relative motion is uniform, and in a straight line, then only vision can detect it positively, although it may be inferred by other cues such as air movement on the fact, or by the doppler effect produced by a passing sound. On the other hand, the stimulus of acceleration, or changing velocity, gives rise to sensations of movement of vestibular or proprioceptive origin which together with reflex ocular effects, gives rise to a group of visual sensations of movement usually referred to as illusions. The term "illusory movement," however, is probably best limited to the third group in which movement is seen, although there is no demonstrable objective change either in the position of the observer's eye or in the relative position of the test object. Thus, the situation in which an observer in a stationary train sees another, but

moving, train and falsely believes that he himself is moving, is often called "illusory movement." But it is not the visual movement which is illusory, for that relative movement is real and if the acceleration on a purely hypothetical railway is subthreshold, then there is no information on which it is possible to decide whether one is really moving. This is, therefore, rather a case of mistaken identity than one of illusory movement.

229. Wierwille, W. W. and Williges, R. C. Survey and analysis of operator workload assessment techniques. Systemetrics, Inc. Technical Report S-78-101, September 1978.

230. Williams, L. G. Target conspicuity and visual search. Human Factors, 1966, 8, 80-92.

A general measure of target conspicuity is proposed for predicting the level of search performance as a function of spatial and temporal variables. The probability of locating a target is shown to depend on two factors: target conspicuity, the rate at which the observer can scan the field, and information input rate, the rate at which the field is presented to the observer. Predictions of the effects of such factors as size, scale, rate of movement, and time available, are made for reconnaissance displays. Some experimental support is presented.

231. Williams, L. G. Studies of extrafoveal discrimination and detection. Visual Search, Symposium conducted at Spring Meeting, 1970, Committee on Vision, National Research Council, National Academy of Sciences, Washington, D. C., 1973.

Because it is found useful to distinguish between two kinds of acquisition, two kinds of search tasks are perceived, two models of the search process, and two experimental paradigms. In the first type of acquisition, targets are superthreshold extrafoveally. By this is meant that an object several degrees away from the subject's line of sight is recognized as a potential target (that is, a member of the target class). In the second type of acquisition, the target is at threshold extrafoveally because it is small, its contrast is low, or it is embedded in the background structure. In the present discussion, we shall consider only suprathresthe subjects fixate only those objects in the specified target class. Performance depends on extrafoveal discriminability of the target from other objects, the subject's fixation rate, and identification difficulties that affect fixation rate.

232. Williams, L. G. A study of visual search using eye movement recordings. Supported by Engineering Psychology Branch, Office of Naval Research, Technical Report, March 1967.

This report discussed two experimental investigations, one on the effect of target-size specifications, the other on the effect of color specification. It was found that when the size of the target was specified to the searcher, the likelihood of a fixation falling on an object in the search field depended almost entirely on the ratio of the specified target size to the object size. The likelihood of fixation was found to be essentially independent of the range of object sizes in the field, the average size of the objects, or the lightness of the objects in the field. The largest objects in the field were discriminated better than the other sizes. Other differences between sizes were minor.

233. Williams, L. G. and Borow, M. S. The effect of rate and direction of display movement upon visual search. Human Factors, 1963, 5, 139.

A study was undertaken to determine the effects of rate and direction of display movement upon the time to find an alphabetical target. Subjects searched for targets which always remained present in a display which moved but did not change. Display speeds somewhat faster than 8 deg/sec angular velocity (2 in/sec viewed at 15 in) were associated with decrements in performance. At higher rates of movement, search times for horizontally moving displays were lower than those for vertically moving displays. It is recommended that high-speed displays move horizontally when compatible with other system needs.

234. Woodson, W. E. and Conover, D. W. (Eds.) Human engineering guide for equipment designers, 2nd ed. Berkeley, CA: University of California Press, 1964.

235. Young, L. R. and Sheena, D. Methods and designs: Survey of eye movement recording methods. Behavior Research Methods and Instrumentation, 1975, 7, 397-429.

This paper reviews most of the known measuring techniques for measuring eye movements, explaining their principle of operation and their primary advantages and disadvantages. The five sections of the paper cover the following topics: (1) types of eye movement, (2) characteristics of the eye which lend themselves to measurement and the principles and approaches to the measurement of eye movements, (3) practical methods of measurement with special attention to the new techniques, (4) general considerations guiding a selection of method, and summarizing the major findings in a concise table.

236. Zaitzeff, L. P. Visual target acquisition prediction: A basic mathematical model. Boeing Company Technical Report No. D6-57142TN, March 1967.

This document outlines a mathematically specific approach to visual target acquisition. The acquisition sequence is divided into search and classification (identification) phases separated by the act of detection. Search is limited to an area forward of the observer, determined by his/her visual capabilities and by the physical and optical characteristics of the target and its surroundings. This area is referred to herein as the "relative" search area. Once a target falls into a relative search area, the temporal length of search is determined by a detection function, which incorporates target-background characteristics, a masking function, the target (stimulus) density, the extent of the relative search area, and an average detection rate. Classification time (which has a derived minimum of one second) is presumed to be dependent on target-background characteristics and some measure of the complexity of the target. The model predicts probability of acquisition as a function of range for a competent and efficient observer under a number of possible input conditions. Conditions other than those specified are presumed to be ideal. The predicted ranges and probabilities will be used to provide comparative data for validation and further development of the model.